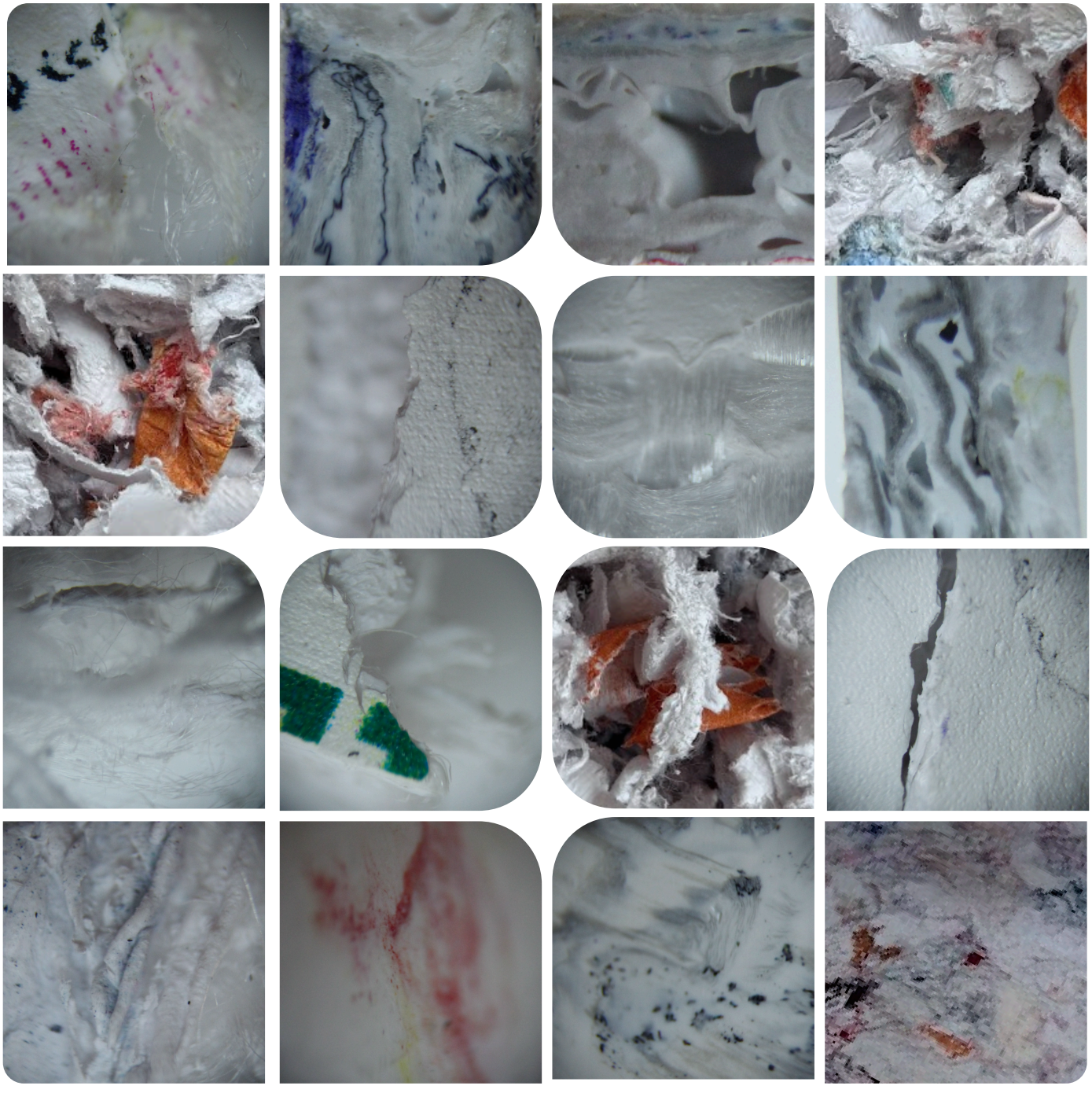
Circularity within the Print & Sign industry:

Shedding light on the story behind
the recycling of PVC banners.



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MSc. Integrated Product Design
Industrial Design Engineering

May 2026
Delft University of Technology

Master Thesis
Circularity within the Print & Sign industry:
Shedding light on the story behind the recycling of PVC banners.

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May 2026

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In collaboration with
Horizonteer
Client mentor: Rein Hintzen

Preface

This project aligns with the core passion of trying to make sustainable changes, big or small, to my surroundings. I have often said that the topic does not matter in which I keep myself busy, as long as it has something to do with sustainability and adding a positive change to the system at hand.

The journey of this thesis has been one of perspective shifts. I initially approached the challenge as a technical material problem, looking for a perfect recycling solution that does not yet exist. However, the process taught me that sustainable design is as much about psychology, communication, and system orchestration as it is about material science. My focus therefore shifted from changing the problem at the start of the system to changing the information structure between the stakeholders who produce and procure PVC banners and convince them to chose for recyclates. The developed Strategic Roadmap, Guidebook, and Texture Board represent a necessary compromise: a pragmatic bridge to close the material loop today while working toward a more regenerative system tomorrow.

This project would not have been possible without the invaluable support and guidance of many people.

First, I want to express my deepest gratitude to the team at Horizonteer, my collaborating innovation agency. Thank you for welcoming me into your workflow, providing me with the autonomy to explore this complex topic and grounding my academic aspirations in industrial reality. Special thanks to my company mentor, Rein Hintzen, for your consistent feedback and faith in the project's direction.

To my university supervisors, Shahrokh Nikou and Puck Bos, thank you for challenging my assumptions and pushing me to elevate the academic rigor of my framework. Your guidance helped me navigate the complexity of systemic barriers and theoretical ceilings.

Finally, I want to thank my family and friends for their emotional support and patience throughout this intensive graduation process. Your encouragement provided the resilience needed to see this project through to completion.

This thesis represents a small but necessary step toward lighting the path to a circular print industry. I hope these findings provide the clarity and tools required for the industry to take some responsibility for its material choices.

Amber Markus
Delft, May 2026

Abstract

The print and sign industry currently operates on a linear ‘take-make-use-dispose’ model, where a portion of flexible signage, specifically PVC/PET banners, is discarded after a short period of use. Often following a single event lasting an average of 45 days. These banners are characterised as "monstrous hybrids", because the permanent fusion of a PVC coating with a PET woven mesh makes them technically and economically unviable for traditional recycling, resulting in a 97% incineration rate. This research investigates pathways to transition the industry toward a circular economy by optimising the market integration of Sign Again, a rigid composite material made from shredded banner waste.

Employing a mixed methods design approach that uses circular economy as a starting point and combines the Double Diamond and IDEO’s Human-Centered Design frameworks. The study utilised literature reviews, 12 semi-structured expert interviews, co-creation sessions and material testing. The research identifies that the primary bottlenecks to circularity are not technical, but rather economic and systemic, specifically the "economic floor" of cheap virgin plastics and the "systemic ceiling" of fragmented stakeholder communication and policy gaps.

The final design outcomes include a strategic roadmap to guide the industry toward a more CO^2-neutral value chain by 2045, a B2B guidebook that translates complex technical data into actionable procurement information, and a physical texture board designed to bridge the tactile gap and build trust in recycled composites. Ultimately, this thesis proves that by empowering stakeholders with transparent data and physical validation tools, the industry can lower the threshold for sustainable material adoption and transform a persistent waste stream into a valuable resource.

Table of content

1. Introduction **8**

1.1 Problem context 9

1.2 Circular Economy as a design approach 11

1.3 Scope 13

1.4 Research objective 14

1.5 Collaborative partner: Horizonteer 15

2. Literature review **17**

2.1 Research methodology 18

2.2 Material context: PVC/PET banner 19

2.3 End of life 24

2.4 System analysis 29

2.5 Circular principles 34

2.6 Theoretical framework 36

3. Research methodology **41**

3.1 Sampling and stakeholders 42

3.2 Data collection and analysis 43

4. Preliminary results **45**

4.1 Analysis of expert interviews 46

4.2 Thematic analysis of preliminary results 48

4.3 Conclusion 51

4.4 Revision of theoretical framework 53

4.5 Design recommendations 56

5. Design methodology **59**

5.1 Design methodologies 60

6. Results co-creation **68**

6.1 Value mapping 69

6.2 Idea mapping 73

6.3 Pathway mapping 74

6.4 Co-creation session 78

6.5 Designing roadmap

7. Material testing 83
7.1 Banner pull test 84
7.2 Bending test 87
7.3 Tensile strength test 89
7.4 Water absorption test 92
7.5 Screw pull test 94
7.6 Shore test 96
7.7 Conclusion 98

8. Design development 100
8.1 Design vision 101
8.2 Ideation 102
8.3 The Sign Again guidebook 104
8.4 Guidebook validation 106
8.5 The Sign Again texture board 108

9. Results design phase 114
9.1 Strategic roadmap 115
9.2 The Sign Again guidebook 120
9.3 The Sign Again texture board 128
9.4 Implementation plan 135

10. Conclusion 135
10.1 Discussion 136
10.2 Answering the research questions 137
10.3 Literature contributions 138
10.4 Practical implications 138
10.5 Limitations 138
10.6 Recommendations for future works 139

11. Personal reflection 141

12. References 145

13. Appendices 154

Chapter 1.

Introduction

1.1 Problem context
1.2 Circular economy as a design approach
1.3 Scope
1.4 Research objective
1.5 Collaborative partner: Horizonteer

1. INTRODUCTION

1. Introduction

This chapter introduces the context of the problem on which this project will focus and how it affects its system. After which the scope for this research is discussed as well as with the design approach for this project. Lastly, the research question along with the research objective is stated and the collaborating partner company is highlighted.

1.1 Problem context

In the current marketing world it is still common to use physical products for advertising such as flags, banners and LED frames. Figures 1-3 show this as examples. A significant portion of flexible signage (52.3%) is produced from polyvinyl chloride (PVC) and polyester (PET) (Future Market Report, 2025), primarily due to its low cost, high print quality and durability. However, PVC poses substantial environmental and health concerns during end of life stages, including carcinogenic outcomes and reproductive impairments (Cuc & Secan, 2024; Ecology Center, 2025). These concerns are due to the release of noxious gases during the incineration processes of plastics, PVC needs to be burned at high temperatures of around 300°C which effects the immediate environment and also releases harmful pollutants such as sulphates and nitrates (Takeshita et al., 2004). These gases are heavier than air and thus reduce the supply of oxygen. The chlorine in PVC leads to the creation of dioxins, which are highly toxic, persistent organic pollutants. They are subsequently released into the environment (Yang et al., 2021). When PVC ends up on landfills, the material gradually leaches into the soil, contaminating it (Lewandowski & Skórczewska, 2022; Siddique et al., 2008). It becomes clear that these materials, especially PVC, have a serious negative impact on the environment.



Figure 1. *Flags (iFocus, 2025)* ***Figure 2.*** *PVC/PET banner (FSEID, 2025)* ***Figure 3.*** *LED frame (Probo, 2025c)*

The existing business model within the print and sign industry contributes to this environmental impact. Most PVC/PET banners are discarded after a short period of use, often after a single event with an average of 45 days (Saatcioglu & Venkatraman, 2024), reflecting a linear consumption pattern. Besides this, there is little opportunity for a sustainable end of life. There is still a lack of a take-back system for PVC/PET banners (European Environment Agency, 2024), making recycling difficult for the average consumers and even for large events where these banners can pile up quickly in waste bins. In the rare case when banners are taken for recycling, the existing recycling processes for them are currently suboptimal. Chemical recycling has proven inefficient as the proportion of PVC to PET is very low, resulting in little material recovery. Besides this, operational costs are high and thus not economically viable. Mechanical recycling often leads to heterogeneous and visually inconsistent materials, which are difficult to market in large quantities (Cuc & Secan, 2024). These complications arise from how the banners are manufactured, the final product consists for a composite structure: PET mesh with a thin coat of PVC on both sides, creating fused layers that are difficult to separate for recycling.

Even when recycling technologies are applied, as mentioned before, the system itself does not support efficient collection or reuse. There is little incentive for companies or consumers to return used banners to producers or recycling centres and it is unclear with whom the responsibility lies. Producers, consumers and governments all play a role. Current European legislation will require at least 30% of products in the print and sign industry to consist of recycled materials (Plastics Europe, 2023), placing greater responsibility on producers. However, consumers also influence sustainability outcomes through purchasing decisions and creating awareness. The lack in policy and stakeholder collaboration prevents a circular material flow (Ramboll, 2021).

Some innovative initiatives, such as Sign Again, have begun using mechanically shredded PVC/PET banner waste as a raw material for new products such as signage, flooring and tiling (Sign Again, 2025). While promising, this process remains costly, results in heavy yet flexible end products unsuitable for all applications and not well known under potential users. Other repurposing initiatives have also been growing, transforming PVC/PET banners into bags, apparel or other consumer goods (see Figures 4-6), yet these remain limited in scale (Saatcioglu & Venkatraman, 2024). This raises the question of how to maximise the material value of discarded banners and what alternative applications might exist for PVC/PET banner waste.



Figure 4. *Backpack (Freitag, 2026)*



Figure 5. *Outdoor seating (Drayson, 2020b)*



Figure 6. *Bottle holder (Calluna upcycling, 2025)*

1.2 Circular economy as a design approach

Circular economy presents a counterpoint to the traditional linear 'take-make-use-dispose' model. It emphasises maintaining the value of materials for as long as possible through strategies such as sharing, leasing, reusing, repairing, refurbishing and recycling (European Parliament, 2023). This approach aims to minimise waste generation by closing material loops and extending product lifespans. What this looks like for a system is visualised in the butterfly diagram, see Figure 7. Organic and renewable materials are shown on the left hand side and it explains which steps need to be taken to keep materials within the system. The same goes for finite materials, shown on the right hand side. In this report, PVC/PET banners are seen to be made out of finite materials.

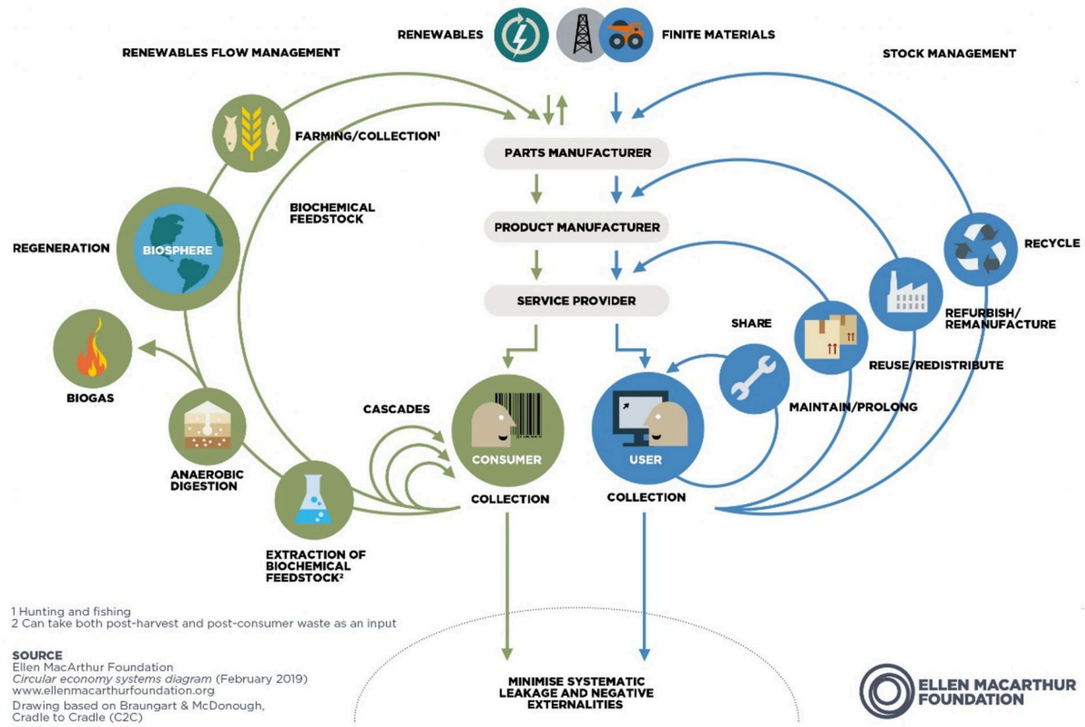


Figure 7. *The butterfly diagram, visualising the circular economy (Ellen MacArthur Foundation, 2021)*

In contrast to circular economy, the linear model often results in short lived products and planned obsolescence (EFS Consulting, 2025). Such a linear model for plastic packaging is shown in Figure 8 on the following page, where most of the material within the system is discarded through incineration, landfill or does not make it into any disposal system thus leaking directly into the environment. In a linear model no or only a small percentage of material is collected to be recycled. This material can be repurposed or be brought back into the same system, closing the material loop. While some companies in the print and sign industry are beginning to promote more sustainable printing practices, such as creating reusable or multi-purpose designs (Exposure Company, 2025), a large proportion of printed materials, particularly banners for specific events (e.g. birthdays, festivals, exhibitions), remain single use (Saatcioglu & Venkatraman, 2024). The continued preference for PVC, driven by its low cost and durability, perpetuates these environmental challenges.

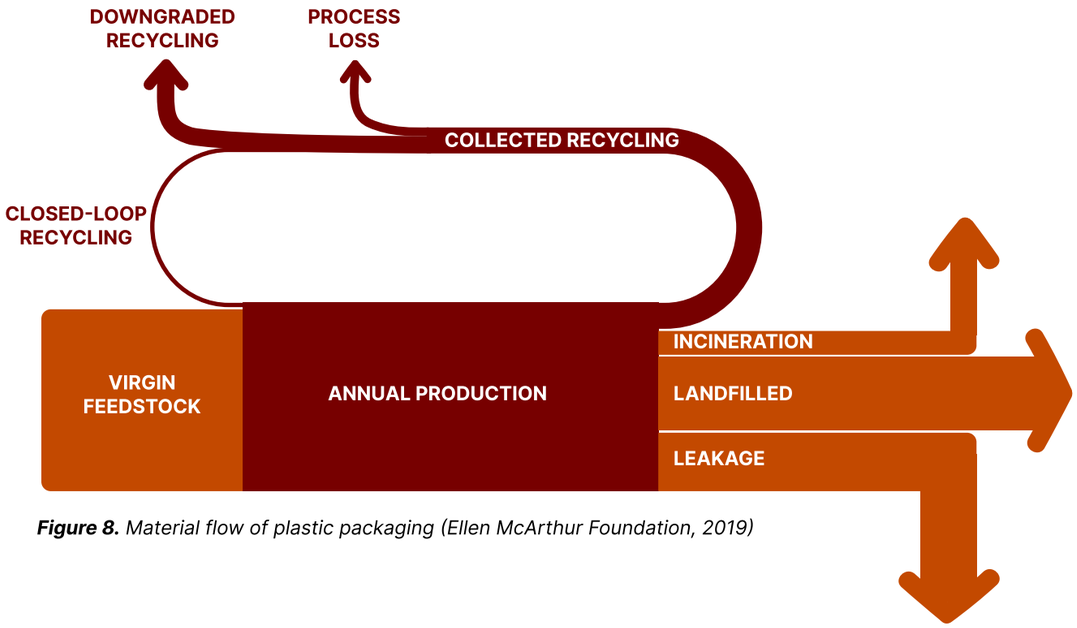


Figure 8. *Material flow of plastic packaging (Ellen McArthur Foundation, 2019)*

Businesses play a crucial role in the transition to a circular economy. According to Haffmans et al. (2018), companies can create value by slowing down product and material flows, keeping resources in use for longer periods and recovering them efficiently at end of life. In the context of PVC/PET banners, this involves establishing organised material collection systems, optimising reverse logistics and developing new services or business models around reuse and recycling. By maintaining control over material streams, companies can reduce environmental damage while potentially lowering operational costs and creating new market opportunities.

This project will use Circular Economy to approach the research and design phase, taking the entire lifecycle of the PVC/PET banner into consideration. By focusing on value retention, stakeholder fragmentation and systemic barriers, the design process will aim to overcome the print and sign industry's limitations. Applying circular principles will guide the development of a sustainable concept that will facilitate the adoption of circular alternatives like Sign Again. This ensures a holistic understanding of the problem, yet helps the project focus on finding a solution to help close the loop.

1.3 Scope

This research explores the potential of transitioning toward a more circular economy within the print and sign industry. This is done by addressing the systemic barriers that prevent the adoption of recycled materials. Specifically, the study investigates how to bridge the knowledge and communication gap surrounding Sign Again, a sheet material produced through the mechanical recycling of shredded PVC/PET banners, to facilitate its adoption as a sustainable alternative.

The scope of this thesis is defined by the following core aspects:

Boundaries and limitations
The research is limited to mechanically recycled PVC/PET banner waste processed through the Sign Again method. It does not cover chemical recycling or other recovery processes. Furthermore, the development of the guidebook is conducted on a conceptual and prototype level. The focus is to apply the findings of the built theoretical framework into a concept.

Technical feasibility and information design
The study first identifies important material properties through various material tests, used to compare Sign Again with conventional industry materials. This technical data is then translated into a conceptual guidebook. The scope includes assessing the tool's usability, clarity and ability to effectively communicate the unique properties of Sign Again (e.g. strength, aesthetics, circularity, flexibility, ect.) to technical clients and stakeholders.

Systemic and environmental sustainability
The study evaluates the concept's capacity to induce systemic change. The focus lies on its ability to inform stakeholders on circular thinking, thereby encouraging behaviour change. The research aims to validate whether better and more information flow can increase the material recovery rate of PVC/PET banners.

Geographical and market context
The scope is confined to the European print and sign market. It takes into account current and upcoming circular economy legislations, such as the Green Deal and EPR, that affect material recovery. Stakeholder insights, including printing companies, recycling initiatives and end clients, are considered to map the specific barriers that the tool must address.

To achieve these aims, the research utilises the Double Diamond design process combined with IDEO's 3-stage framework (hear, create, deliver). Through iterative rounds of stakeholder feedback a concrete roadmap and concept will be developed. Ultimately, this thesis aims to prove that by empowering stakeholders with transparent, comparable and actionable data, a dedicated guidebook can effectively lower the threshold for adopting sustainable materials and help the industry's transition from a linear to a circular model.

1.4 Research Objective

The objective of this research is to develop and test a theoretical framework that helps designers establish sustainable recovery practices for PVC/PET banner waste, within the print and sign industry. Through literature research and expert interviews, the framework will inform pathways to enhance the circularity of PVC/PET banner use and its disposal.

Main research question:
How can the Sign Again panel material be optimised in the market to move closer to a fully circular system for PVC/PET banner waste within the print and sign industry?

Sub-Questions:
1. What system interventions could enable more sustainable practices for banners across the value chain?
2. What are the environmental and technical limitations and opportunities of PVC/PET banners throughout their lifecycle?

To find an answer to the questions stated above, the project gathered information through several channels: literature research, qualitative interviews, co-creation sessions and material testing. To guide the design process the double diamond combined with the IDEO (HCD) methodology was used. The output of the research is to design a roadmap and concept using Sign Again, to improve the circularity of PVC/PET banners (waste) for the value chain in the context of sustainable recovery practices.



Figure 9. *Shredded PVC banner*



Figure 10. *Sign Again panel*

1.5 Collaborative partner: Horizonteer

This graduation project is conducted in collaboration with Horizonteer (Figure 11 shows the whole team), an innovation and design agency based in Utrecht, the Netherlands. Horizonteer specialises in helping small and medium sized entrepreneurs (SMEs) and companies to accelerate through sustainable innovation and make strategic, future-proof product decisions (Horizonteer, 2026).

Horizonteer operates at the intersection of design, strategy and technology, this ensures their products are thoughtful and actually work to create impact in practice. Their mission is to assist companies that are facing shifting market demands, new sustainability regulations and the need for circular business models. They provide expertise across three main domains.
1. Product strategy and direction: developing market analyses, value propositions and innovation roadmaps to secure future growth.
2. Product design and realisation: conducting user research, prototyping (both digital UX/UI and physical engineering) and usability tests.
3. Sustainable and circular product design: applying eco-design principles, preforming Life Cycle Assessments (LCA) and navigating complex environmental regulations to minimise material footprints.

For this thesis, Horizonteer acts as the facilitating industry partner. Their experience in guiding companies from linear, traditional practices toward circular, sustainable models aligns perfectly with the objective of this research. While the print and sign industry struggles with the complex transition away from virgin PVC/PET banners, Horizonteer provides the necessary methodological framework, combining a fresh, external perspective with the deep expertise in sustainable product design and user-centric problem solving.

During the project, inspiration will be taking from their previous projects, perspectives and approaches. Some examples are: prototyping, transition management, chain collaboration, roadmap, strategy, data and user research. Horizonteer's multidisciplinary approach will be leveraged to validate the research findings, test assumptions with real world stakeholders and ensure that the final deliverable is not only theoretically sound but also actionable for businesses striving to improve their circularity.



Figure 11. *Horizonteer team (Horizonteer, 2026)*

Chapter 2.

Literature review

2.1 Research methodology
2.2 Material context: PVC/PET banner
2.2.1 Composition and production
2.2.1.1 Material composition
2.2.1.2 Production process
2.2.1.3 Material and market context
2.2.2 Environmental impact
2.2.3 Alternative materials
2.3 End of life
2.3.1 Incineration and landfill
2.3.2 Recycling challenges
2.3.3 Existing reuse and repurpose
2.3.4 Alternative methods
2.4 System analysis
2.4.1 Stakeholder map
2.4.2 Market and policy context
2.4.3 System map
2.5 Circular principles
2.5.1 Circular economy
2.5.2 The R-Ladder applied
2.6 Theoretical framework
2.6.1 Deriving domains
2.6.2 Proposed barrier framework

2. LITERATURE REVIEW

2. Literature review

This chapter provides an analysis of the current state of the print and sign industry, focusing specifically on the lifecycle of PVC/PET banners (or PVC flex banners hereafter referred to as banners or PVC banners). By examining the material composition, production processes, product usage and end of life scenarios, the root causes of the linear waste problem are identified. Furthermore, the chapter explores relevant theoretical frameworks, such as the Circular Economy, the R-Ladder and maps the complex stakeholder network to define the systemic barriers that currently hinder sustainable innovation. The important literature review findings are visualised in a system map and furthermore a theoretical framework is developed based on the complete research.

2.1 Research methodology

To address the research question a thorough literature review was conducted. The primary aim was to define a research gap concerning the waste recovery and end-of-life management of PVC banners within the print and sign industry.

The academic databases Google Scholar and Web of Science were utilised to identify relevant scientific literature. To gain a large quantity of relevant results, the following groups of keywords were used, combined together using the Boolean operator "AND", while terms within the groups were separated by "OR":

(“pvc banner*” OR “banner” OR “flex*banner*” OR “PVC banner*” OR “PVC flex* banner*”)

(“recycling” OR “end of life” OR “end-of-life” OR “recycl*” OR “reuse” OR “repurpose” OR “redesign” OR “alternative*” OR “prototype” OR “post-consumer” OR “post consumer” OR “waste”)

(“circular*” OR “sustainab*” OR “systemic value” OR “organi*ation” OR “roadmap” OR “system”)

(“* print* * industry” OR “* sign* *industry” OR “print and sign”)

(“value chain” OR “value-chain” OR “stakeholder*” OR “partner”)

The initial screening process involved reviewing the titles of the generated search results. If a title indicated relevance to the research scope, the abstract was then scanned. Through this process, 35 core papers were selected and read in full to form the foundation of the literature review. Furthermore, the "snowballing" method was applied to discover additional relevant literature; key citations and concepts identified within the initial 35 papers were traced and subsequently analyzed to deepen the understanding of the print and sign industry's specific challenges.

2.2 Material context: PVC/PET banner

To understand the environmental impact of banner waste, it is essential to first analyse the material of which it is made. This sub chapter examines the physical and chemical composition of PVC banners, exploring the specific properties that make them the industry standard for outdoor advertising. It further details the production processes of the primary components, polyvinyl chloride (PVC) and polyethylene terephthalate (PET), to highlight how their complex, composite structure creates inherent challenges for recycling and circularity.

2.2.1 Composition and production

PVC banners are the industry standard for low cost outdoor marketing due to their print quality and durability. They offer robust resistance to water, fungus, fire, UV radiation and freezing weather (Cuc & Secan, 2024; Uttaravalli et al., 2021). Consequently, PVC is widely employed to fabricate large scale outdoor advertising signs, truck covers and flags.

2.2.1.1 Material composition

The banners consist of a multi layer laminated structure that combines different polymers. Typically, a PET base fabric is sandwiched between two layers of PVC film (Saatcioglu & Venkatraman, 2024), see Figure 12. The PVC layers are composed of resin, calcium carbonate ($CaCO_3$), stabilisers, pigments and plasticisers such as phthalates that provide flexibility (Cuc & Secan, 2024). These additives improve performance but introduce environmental and health hazards. See Appendix B.1 for a diagram of PVC manufacturing and by-product release. The PET reinforcement layer provides tensile strength and dimensional stability, meaning resistance to warping, shrinking or expanding. Reference Appendix B.2 for a detailed visual on PET production.

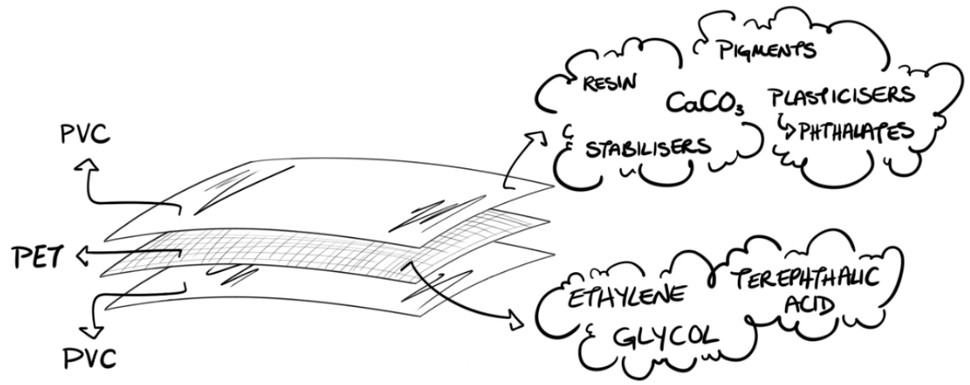


Figure 12. *Image of composition of PVC banners illustrates the layers*

The specific concentration of all these ‘ingredients’ determine the banner’s final properties. A typical composition breakdown is shown in Table 1. However, these concentrations can differ per banner and what function they have. By varying the ratio PVC to PET different physical properties can be created, such as making the product either more flexible or stronger. A truck cover should be stronger and so a higher PVC resin concentration would be required than a standard advertising banner (BondCote Corporation, 2014).

Table 1. *Typical chemical composition of PVC banners (Zhejiang Ganglong New Material Co., Ltd., 2025)*

Ingredient	Concentration	Function
PVC resin	30.43%	Primary polymer for outer layer
PET	29.41%	Internal fabric reinforcement layer
Calcium carbonate ($CaCO_3$)	22.82%	Filler materials reduce cost and improve opacity
Plasticiser (DINP)	12.78%	Provides flexibility
Titanium dioxide (Tio_2)	2.43%	White pigment for brightness and UV resistance
Stabiliser	1.52%	Prevents degradation from heat and light
Else	0.61%	Other additives

While these additives, found seen in Figure 12 and listed in Table 1, allow PVC to be moulded into virtually any shape, they introduce environmental challenges. For instance, the PET reinforcement creates a strong bond with the PVC film (Liu et al., 2022), making material separation challenging during end of life recycling. Chapter 2.3 elaborates further one this issue.

2.2.1.2 Production process

There are three main production methods to make PVC banners (Admateiral, 2023), they allow the creation of durable, lightweight banners with the resistances required for extended outdoor use. Knife-scraping involves applying PVC slurry evenly on both sides of a fabric substrate, followed by a drying process. This typically produces banners with high tensile strength and peel resistance. China is the main producer of banners made by knife-scraping. Second is calendering, this is where PVC powder and liquid plasticiser are mixed and then bonded to the fabric. This is done under high pressure using heated rollers. This results in strong, flexible and consistent in quality banners with a better surface flatness. Lastly there is the lamination production process. PVC film is laminated to PET cloth from both sides using hot rollers. This is then cooled and formed. This process provides excellent ink absorption and vibrant colours. Most of the banners sold on the market are made through this production process (Tome, 2024), see Figure 13 for a visualisation of this process.

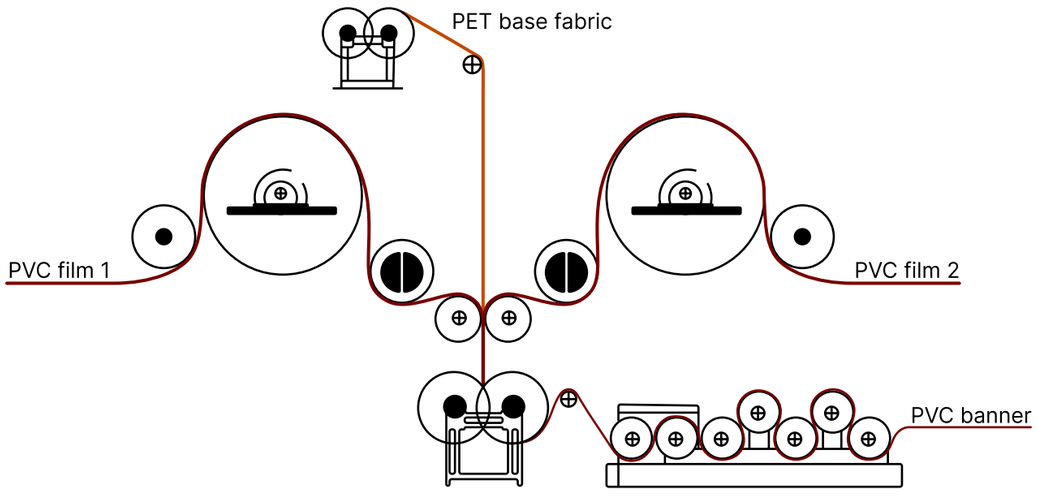


Figure 13. *Visualisation of the lamination production process (FXTarpaulin, 2024)*

2.2.1.3 Material and market context

The global market for banners was valued at US $9.53 billion in 2024 (TechSci Research, 2026). The market is expected to further expand at a Compound Annual Growth Rate (CAGR) of 5.0% from 2025 to 2030. This is illustrated in Figure 14, where the printed vinyl market includes banners, billboards, vehicle wraps and signage.

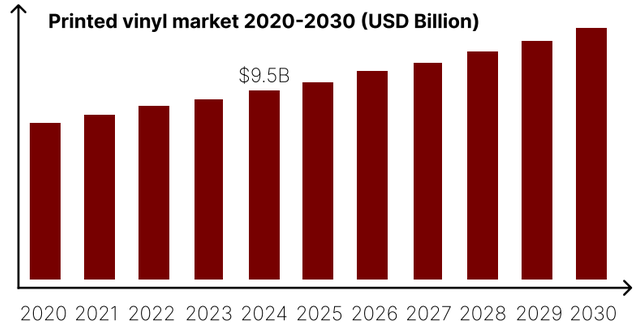


Figure 14. *Predicted market for printed vinyl (TechSci Research, 2026)*

PVC is considered a universal polymer because of its low cost, desirable properties and versatility. While it is predominantly used in long-life products such as pipes, window frames and flooring (Ciacci et al., 2017; Sadat-Shojai and Bakhshandeh, 2011), it is also essential for short-life products like packaging, cleaning products and medical devices. PVC can be used with a wide range of additives to produce both flexible and rigid thermoplastics and can be moulded into virtually any required size and shape using methods such as injection moulding, calendaring, roto-moulding, extrusion, hot pressing and plastisol techniques (Titow, 2012).

PVC alone is currently the third-largest category of plastic produced both globally and in Europe (Plastics Europe, 2024). The global PVC market size was estimated at USD 8.54 billion in 2023 and is projected to reach USD 10.82 billion by 2030, growing at a CAGR of 3.6% from 2024 to 2030 (Grand view research, 2026), see Figure 15.

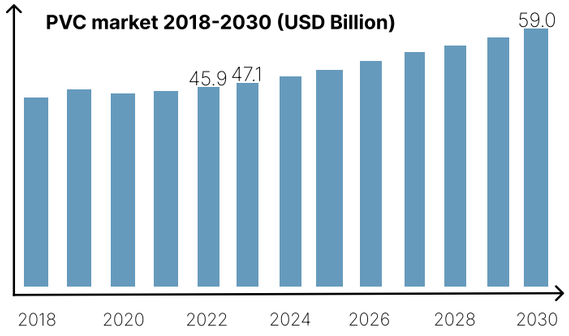


Figure 15. *Predicted market for PVC (Grand view research, 2026)*

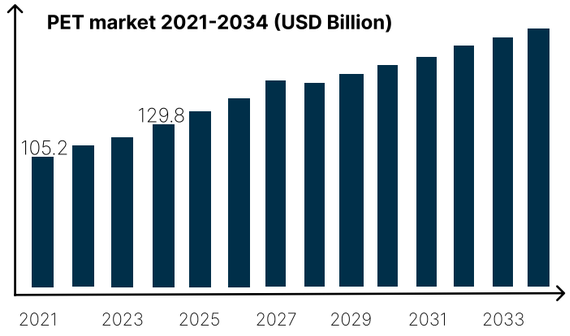


Figure 16. *Predicted market for PET (GMI et al., 2025)*

PET is considered a versatile polymer due to its exceptional mechanical strength, chemical resistance and recyclability. While it is predominantly used in long-life products, such as clothing, it is also essential for short-life products like beverage bottles and food packaging (The Essential Chemical Industry, 2016).

The market for polyester is substantial and continues to expand. The global polyester fiber market was valued at approximately USD 129.8 billion in 2024 and is forecast to reach USD 207.4 billion by 2034 (GMI et al., 2025), see Figure 16. In the specific niche of polymer-coated fabrics, polyester is projected to capture a 32% market share by 2035 due to its durability and cost-effectiveness. Currently, PET ranks as the eight most demanded polymer globally (Plastics Europe, 2024).

2.2.2 Environmental impact

The environmental burden of banners made from PVC and PET arises from both material composition and systemic inefficiency. During production, PVC's chlorine-based chemistry releases vinyl chloride monomer (VCM) and dioxins, both of which are carcinogenic and persistent in the environment (Everard, 2020). PET production, although halogen-free, is heavily dependent on fossil fuels and responsible for approximately 1.8–2.5 tonnes of CO_2-equivalent per tonne produced (Shen et al., 2010). Together, these materials contribute significantly to climate change and air pollution before they even reach the market.

It is important to distinguish between pure polymers and composites when assessing their end of life viability. For instance, pure, rigid PVC products, such as construction pipes or specific medical devices, go through established recycling infrastructure and have relatively high recovery rates. However, banners are fundamentally different. They are a hybrid consisting of a permanent fusion of a PVC coating and a PET woven mesh.

When fused together in this manner, PVC and PET present virtually no safe end of life solution. If landfilled, the plastics will never fully degrade, persisting in the environment for thousands of years while slowly leaching hazardous additives into the groundwater (Scott et al., 2005). When incinerated, the PVC component releases corrosive hydrochloric acid and toxic dioxins. Although modern waste to energy plants utilise advanced exhaust scrubbers to absorb and filter these gases, this process is highly expensive and results in hazardous fly ash that still requires specialised toxic waste disposal (Dzięcioł & Huzar, 2016; Quina et al., 2008). Furthermore, both during the use and disposal phases, the plastics can fragment into microplastics that accumulate in soil and aquatic ecosystems (Gewert et al., 2015).

This hybrid composition also destroys the recyclability of the PET component. While pure PET is highly recyclable, and countries like the Netherlands achieve excellent recovery rates for pure PET packaging through dedicated infrastructure (Brouwer et al., 2018; Welle, 2011), this success does not translate to the sign industry. It is currently economically and mechanically unviable to cleanly separate the inner PET mesh from the outer PVC coating. Consequently, the high recyclability of PET and equally for PVC is entirely nullified by its application in the banner.

Ultimately, the manufacturing of banners merges these polymers into a single product, effectively locking two otherwise recoverable materials into a cycle of waste. Furthermore, the short lifespan of these banners, combined with the absolute absence of effective separation strategies, creates a strictly linear and environmentally harmful system.

2.2.3 Alternative materials

Consumers currently have several options regarding the material composition of their signage. For instance, Dibond®, also known under the names Alupanel and Alubond, is a sandwich panel consisting of three layers: two aluminum outer layers with a polyethylene core in between (De Vos, 2024). One of the major advantages of Dibond® is that it is highly resistant to weather, wind and temperature fluctuations. Another popular option is Forex, which is a lightweight, rigid plastic sheet composed of polyvinyl chloride (PVC) foam (Probo, 2925b). For paper based display needs Re-board®, also known as honeycomb cardboard, provides a light, strong and fully recyclable cardboard alternative (Re-Board® Technology, n.d.). Additionally, High Pressure Laminate (HPL) boards are made from a combination of paper layers and phenolic resin, finished with a durable top layer of melamine resin (Probo, 2025d). Figure 17 shows how these materials compare to each other based on specific material properties. Although all these alternatives exist, they do not compare to the valued properties of the PVC banner; cheap, strong and flexible. Meaning that the latter option will often be chosen over other, maybe more sustainable, options (Leatherbarrow, 2023).



Figure 17. *Material comparison of Sign Again and alternatives* (Sign Again, 2026)

Investigations into alternatives to replace PVC/PET composites have highlighted recyclable materials, such as; polypropylene (PP), polyethylene terephthalate (PET) and thermoplastic polyolefins (TPOs), as well as bio-based materials like polylactic acid (PLA). Among these, mono-material PET stands out because the resin is already utilised in current PVC banners. Unlike composite banners, mono-material banners do not require complex separation processes before recycling. Bio-based variants like bio-polyethylene (Bio-PE) offer another route by reducing fossil fuel dependency. However, they remain chemically identical to standard PE and are therefore not biodegradable (Ramesh Kumar et al., 2020). Selecting an appropriate alternative is rarely a straightforward substitution, it requires a nuanced assessment of lifecycle trade-offs. The optimal choice often depends on variables such as the energy intensity of the manufacturing process, the intended lifespan of the product and the material's degradation profile over time.

Despite these options, environmentally conscious choices currently require a trade-off between material performance and cost. Alternatives often exhibit lower durability or weather resistance compared to PVC and often come at a higher price point. Consequently, demand remains low, stifling the investment and development needed to improve them (Leatherbarrow, 2023).

Emerging approaches also focus on coatings derived from organic waste or cellulose-based composites (Comanita et al., 2015). While promising, these must still meet rigorous industry standards for printability, tensile strength and weather resistance. Ultimately, while alternatives exist, their adoption is hindered by the market's reluctance to compromise on low price, high durability and the flexibility that PVC in combination with PET provides.

Relying solely on material substitution is insufficient to resolve the industry's immediate waste crisis due to the mentioned barriers. While bio-based and mono-material innovations continue to mature, they do not address the vast quantities of hybrid PVC/PET banners currently being produced and discarded. Therefore, alongside the development of alternative virgin materials, a parallel focus must be placed on viable end of life recovery strategies that can process the existing waste stream. Shifting the paradigm from replacing the material to capturing and repurposing the waste itself offers an immediate, pragmatic transition pathway toward a circular economy.

2.3 End of life

As established in previous chapters, the composite nature of PVC banners creates significant barriers to circularity. This section explores the current end of life of banners, exploring what the results are post use and analysing why standard recycling processes fail to capture their value.

2.3.1 Incineration and landfill

Banners are marketed as a cheap, temporary advertising solution and consequently treated as a disposable product. The scale of waste is immense: estimates suggest that upwards of 1.2 million PVC banners are manufactured annually (Drayson, 2020a). Yet, less than 1% of all PVC produced is recycled. This discrepancy results in hundreds of tonnes of material being discarded annually, with the vast global majority ending up in landfills (Cholake et al., 2018).

The primary environmental concern is not necessarily the material's safety during its short usage phase, but its behaviour at the end of life. PVC is fundamentally problematic when discarded, the vast majority of PVC used in the printing industry ends up in landfill. Here, banners persist for centuries. Over time, the plasticisers and additives (such as phthalates) leach out of the composite, contaminating soil and eventually reaching groundwater and oceans (Lewandowski & Skórczewska, 2022; Print Business, 2021; Siddique et al., 2008). It becomes evident that after disposing banners in this manner results in a complete loss in any value that was left in the product or material. Figure 18 visualises how discarding materials in landfills has no potential in gaining any value back for the system and should be avoided at all cost.

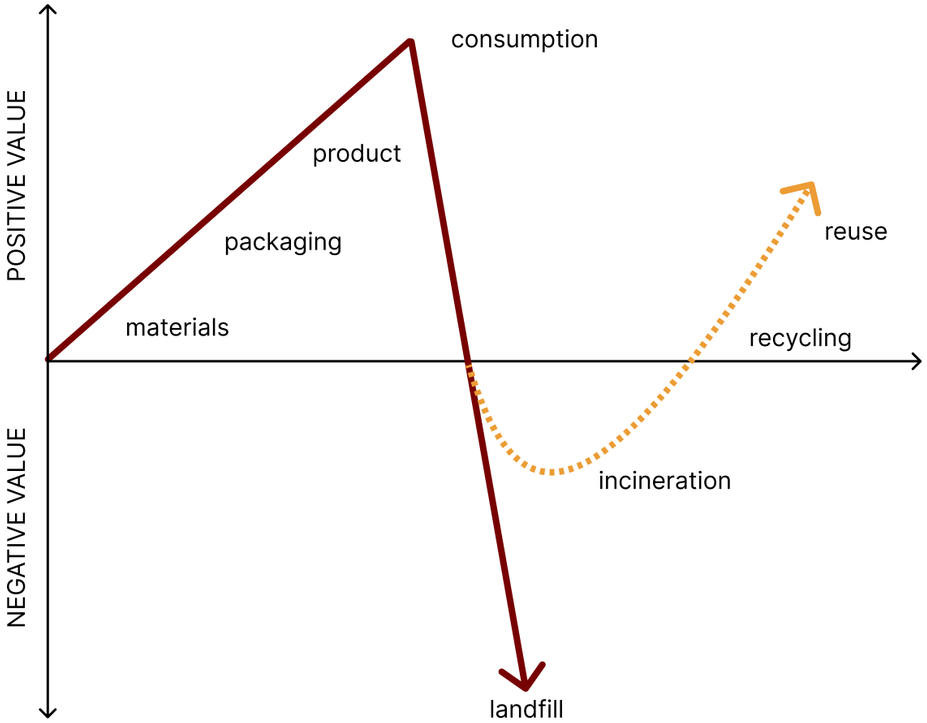


Figure 18. *The typical value decrease of consumer products. Based on a graph from Haffmans et al., 2018.*



Figure 19. *Incineration plant (AU USAnakul, 2025)*

Energy recovery, through incineration, is the most widespread disposal route in Europe (Brown et al., 2000). However, this process emits hydrogen chloride, dioxins and heavy metals, posing severe health and environmental risks (Takeshita et al., 2004; Yang et al., 2021). Even though modern facilities capture some emissions through filtering, incineration causes permanent material loss and should not be classified as recycling. As seen in Figure 18 incineration is the lowest form of value recovered from a product. In the case of PET, incineration releases fewer toxic by-products than PVC but still contributes to greenhouse gas emissions (United Nations, 2024). Consequently, neither of these routes align with circular economy principles, as they either destroy the remaining material value or perpetuate pollution.

2.3.2 Recycling challenges

Recycling PVC banners is technically complex and economically inefficient due to their composite construction. There are two common end of life routes, which are mechanical recycling and chemical recycling.

Mechanical recycling typically involves shredding PVC banners into granulate for reprocessing, but this method is severely hindered by the composite nature of the material. The strong physical bond between the PVC and PET layers makes complete material separation nearly impossible, which leads to a fundamental 'thermal mismatch' during reprocessing. The PVC coating degrades at the relatively low temperatures required to process it (170-190°C), whereas the inner PET mesh requires much higher temperatures to melt (260-280°C) (Ansys, Inc., 2025). Due to these materials no being able to melt together into a cohesive, high-quality product, a problem further compounded by contaminants such as inks, coatings and metal grommets, the resulting recyclate is forced into 'downcycled' applications. Consequently, the material is relegated to lower-value products like traffic cones or floor mats rather than being used to manufacture new banners. This represents a significant fault in the current waste management system, as it fails to keep the value of the recovered material as high as possible (Sadroddini & Hosseini Khorram, 2025).

Chemical recycling, on the other hand, attempts to bypass physical separation by breaking the polymers down into their molecular components through processes like pyrolysis or dehydrochlorination (Ditta et al., 2004; Grigoryeva et al., 2005). While theoretically promising for recovering raw materials, this approach faces severe economic and technical hurdles when applied to PVC. The process releases corrosive hydrochloric acid, which necessitates expensive neutralisation equipment and significant energy input to manage safely. As a result, chemical recycling for PVC is often economically unviable and yields recovered material that is inferior to virgin stock, preventing it from becoming a scalable solution for banner waste (Innotech, 2024).

2.3.3 Existing reuse and repurpose

With traditional recycling routes offering limited solutions, reusing and repurposing have emerged as immediate strategies to extend the lifespan of banner waste. These strategies generally fall into two distinct categories: consumer level repurposing and industrial reprocessing.

Research by Saatcioglu & Venkatraman (2024) highlights the potential of converting used PVC banners into restored value consumer goods such as apparel, footwear and travel accessories (see Figure 20). This approach retains the material's structural integrity, waterproofing and durability, without requiring energy intensive or chemical breakdown.



Figure 20. *Banners recycled into bags at Stichting Stunt*

The material loop is kept small but outside of its own system as the old banner is not made into new banners, illustrated in Figure 21 with the <1% downgraded recycling. These initiatives smartly use the material's aesthetic and divert waste from landfills. This figure also visualises how small the current circular loop is, only 3% of all manufactured banners are recycled in some way. There is a enormous missed opportunity to capture more value.

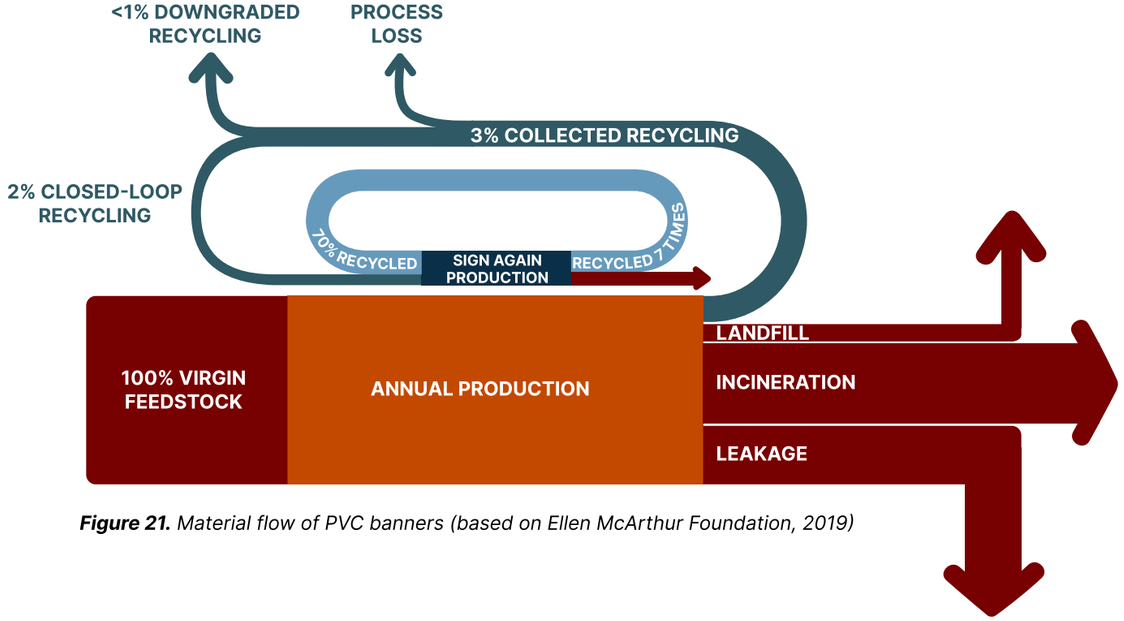


Figure 21. *Material flow of PVC banners (based on Ellen McArthur Foundation, 2019)*

However, the scalability of this approach is severely limited. Banners vary widely in cleanliness and composition or concentration of ingredients, necessitating labour intensive manual cleaning and cutting. Furthermore, the volume of waste produced globally (approx. 1.2 million tonnes annually) far outstrips the demand for tote bags and jackets (Drayson, 2020a). Relying solely on fashion repurposing is not a sustainable solution to the problem. It is a visible solution, but not a systemic one.

To address the volume problem, industrial repurpose initiatives like Sign Again have developed methods to transform shredded PVC/PET composite waste directly into a new rigid material. Instead of separating the PVC film from the PET mesh normally achieved with recycling methods, the entire banner is shredded and heat-pressed into heavy, rigid panels. This could be seen as a way of mechanical recycling without the complete material separation. This method effectively captures kilograms of waste rather than grams. Yet, this solution also faces barriers. The resulting panels are significantly heavier and more expensive than virgin materials. Additionally, market acceptance and consumer perception play critical roles; advertisers often prioritise pristine, blank substrates over the speckled, recycled aesthetic of these panels. Consequently, while industrial repurposing provides a robust technical solution to the waste volume problem, its commercial adoption is bottlenecked by the market's preference for low costs, clean aesthetics and the inherent friction of transitioning to an entirely new material category.

Another industrial strategy for high-volume waste diversion explores the use of shredded waste plastics as aggregates in composite construction materials like concrete. When waste plastics replace mineral aggregates, the proportion of plastic used influences the composite's fresh, mechanical, physical and long-term properties (Bompa et al., 2021). For example, a 15% replacement improves eco-efficiency and sustainability, but it impairs the concrete's fresh state, unless additives are used, and reduces its compressive strength to about 35% of the standard reference material (Bompa et al., 2021). Furthermore, in comparison to normal concrete, the compressive strength decreases by 5%, 15% and 30% when the plastic content is increased to 25%, 50% and 75%, respectively (Bompa et al., 2021). On the other hand, incorporating waste plastics can actually improve the material's overall toughness, allowing it to absorb higher amounts of energy compared to conventional concrete materials (Bompa et al., 2021).

Ultimately, while both consumer-level and industrial repurposing offer viable pathways to divert PVC waste from incinerators and landfills, every current approach requires significant compromises. Whether facing strict limits in scalability, market resistance to new aesthetics and higher costs, or inherent trade-offs in mechanical strength. These strategies highlight that a barrier-free circular solution does not yet exist; instead, the industry must learn to adapt to the unique limitations and properties of repurposed materials.

2.3.4 Alternative methods

Beyond mechanical reuse, alternative end of life methods are being explored to address the chemical complexity of PVC and PET, though most remain in the experimental stage.

Chemical recycling, also known as feedstock recycling, utilises chemical processes to depolymerise plastic waste into fuels or monomer petrochemical feedstocks to create new products (Ragaert et al., 2017). These methods generally fall into three categories: solvent dissolution, which purifies plastics without chemical conversion; enzymatic/catalytic chemical recycling; and solvolysis, which depolymerises plastics using water, glycol or methanol at high temperatures and pressures. Because plastic waste has high amounts of hydrocarbons and insignificant amounts of oxygen, it is highly valuable for fuel or feedstocks. Pioneering companies are already commercialising these solvent-based techniques. For instance, the Dutch company Obbotec has developed a dissolution technology called Selective Plastic Extraction (SPEX) (OBBOTEC, 2024). This process uses specialised solvents to clean plastic waste (but not yet for PVC) down to the molecular level, stripping away internal contaminants like additives, odors, flame retardants and colourants. By purifying the plastics without breaking their polymer chains, Obbotec is able to turn complex waste streams directly back into near-virgin quality raw material with an almost 100% material yield.

However, applying these processes to PVC poses significant hurdles. Advanced chemical methods, such as controlled dehydrochlorination and solvolysis, are energy-intensive and hazardous. They frequently release harmful by-products, including toxic chlorine gas, which necessitates highly expensive containment and neutralisation systems (Lewandowski & Skórczewska, 2022). Currently, the energy required to recover the material often outweighs the environmental benefit and the resulting chemically recycled polymers remain significantly more expensive to produce than cheap virgin alternatives.

Biological recycling or biological deconstruction, utilises microorganisms and enzymes to degrade plastics (Danso et al., 2019; Ru et al., 2020). While institutions are actively funding research to discover new metabolic pathways, this method faces fundamental biological barriers: enzymes require aqueous environments to function, whereas plastics are inherently not water soluble. When applied to PVC, biological solutions have shown very limited promise. Studies utilising mealworms (Tenebrio molitor) demonstrated that while the larvae can ingest PVC, mineralisation rates are exceptionally low, less than 3% over several weeks. Furthermore, the plastic diet often results in incomplete life cycles and high mortality rates for the larvae (Peng et al., 2020; Yadav et al., 2018). Conversely, there is more optimism for the PET component of the banners. The French firm Carbios, for example, has optimised fungal cutinase and lipase enzymes to depolymerise 97% of PET within 24 hours and is currently building a 10,000 metric ton plant to compete against virgin PET markets (Carbios, 2025).

Despite isolated successes like Carbios for pure PET, biological and chemical recycling are not yet economically viable end of life management options at scale for composite materials. Mixed plastic waste presents a massive hurdle, as each different polymer layer in a banner requires a completely different enzyme or chemical pathway to degrade. No scalable solution currently exists that can effectively separate and process the fused PVC/PET composite at industrial levels, the industry lacks a dependable downstream system for disposal. This reinforces the critical need for upstream design changes, such as effectively repurposing existing material waste, material substitution and design for disassembly, rather than relying on future downstream fixes.

2.4 System analysis

To understand why the PVC banner industry remains linear despite the availability of upcoming technical solving part of the problem, the systemic drivers should be analysed. This chapter maps the complex network of stakeholders and examines the market and policy context that currently incentivises waste over circularity.

2.4.1 Stakeholder map

The current system in the print and sign industry is characterised by fragmentation. Unlike circular value chains, there is little to no structural communication between the beginning of the chain (producers) and the end (recyclers).

Initiatives such as RetourMatras are an example of how the use of strong stakeholder connections make it possible to create a circular economy (Matras Recycling Nederland, 2025). In this system it is not complicated for consumers to return their matrass, waste collectors bring is to an specialised recycling centre where the waste product is stripped per material type. The, now raw, materials are then resold to collaborating companies and used in new products. This concrete case study can be an example of how the print and sign industry can improve their stakeholder interconnectedness, close knit collaboration and communication so that the highest amount of material can be recycled.

PVC banner waste involves a complex stakeholder network, Figure 22 show how much interest and power each stakeholder has within the system. Material producers and banner manufacturers choose PVC and PET for their affordability and durability, often overlooking recyclability. Printing companies face client pressure for low-cost, quick-turnaround products, which limit circular innovation. Consumers (eg. event organisers and advertisers) prioritise convenience, cost and aesthetics over sustainability. Recycling firms lack infrastructure to handle composite plastics profitably. Governments are only beginning to introduce regulations mandating recycled content (Plastics Europe, 2023). Fragmented responsibility across the value chain hinders progress. Without collaboration and policy enforcement, such as Extended Producer Responsibility (EPR), the shift toward circularity remains slow (Netherlands Chamber Of Commerce, KVK, 2025).

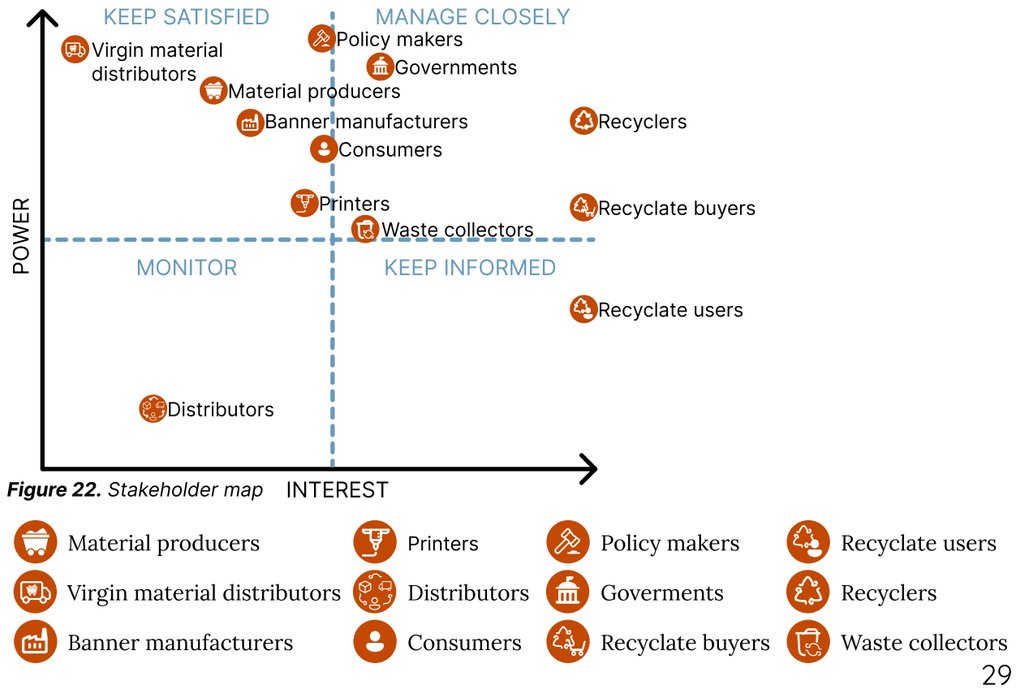


Figure 22. *Stakeholder map*

2.4.2 Market and policy context

The transition to a circular system is heavily influenced by the broader market and regulatory environment. Currently, economic incentives and policy enforcement are misaligned. The banner market is driven almost exclusively by price per square meter and its strong material properties. The influx of low-cost PVC and PET composites (largely from Asian markets) has set a price floor that European circular innovations struggle to compete with. Due to the external costs of disposal (such as pollution and landfill fees) not being reflected in the purchase price, virgin PVC remains artificially cheap compared to recycled alternatives. This economic barrier essentially locks out sustainable materials, as few consumers are willing to pay the higher price for circularity without a functional or regulatory benefit.

Regulatory pressure is growing to correct this market failure. However, the banner industry often falls into a regulatory grey area, it is not strictly classified as packaging (falling under the Packaging and Packaging Waste Regulation, PPWR) (European Commission, 2022) nor is it fully covered by standard textile regulations. Despite this, upcoming legislation is expected to close these gaps through several interconnected European policy frameworks.

The European Green Deal is an overarching policy framework which sets the ambitious binding target of making Europe climate neutral by 2050 (European Commission, 2019). It fundamentally challenges linear 'take-make-use-dispose' models by demanding that economic growth is decoupled from resource use. This creates top down pressure on all manufacturing sectors, including print and sign, to drastically lower their carbon and material footprints.

The Circular Economy Action Plan (CEAP) serves as a core building block of the Green Deal, the CEAP translates these climate goals into specific material strategies (European Commission, 2020). It focuses heavily on how products are designed, promotes circular economy processes, and targets resource intensive sectors like plastics and textiles. The CEAP explicitly aims to ensure that resources are kept in the EU economy for as long as possible, pushing industries toward mandatory recycled content and design-for-disassembly.

Th Extended Producer Responsibility (EPR) acts as the practical enforcement mechanism for the goals outlined in the Green Deal and CEAP. EPR schemes are increasingly shifting the financial and logistical burden of waste management back onto producers (Netherlands Chamber of Commerce, KVK, 2025). While EPR has been successfully implemented for complex waste streams like mattresses and electronics, strict enforcement for printed signage is currently lacking. Without a mandatory take-back fee or an eco-modulated tax on non-recyclable composites, producers currently lack the financial incentive to transition away from cheap virgin PVC.

In conclusion, the system is stagnant not only because of a lack of technology, but also because the economic signals (cheap virgin material) and policy signals (lack of strict EPR enforcement) do not yet force stakeholders to collaborate and adopt circular alternatives.



Figure 23. *Stack of discarded banners (Re-banner, 2025)*

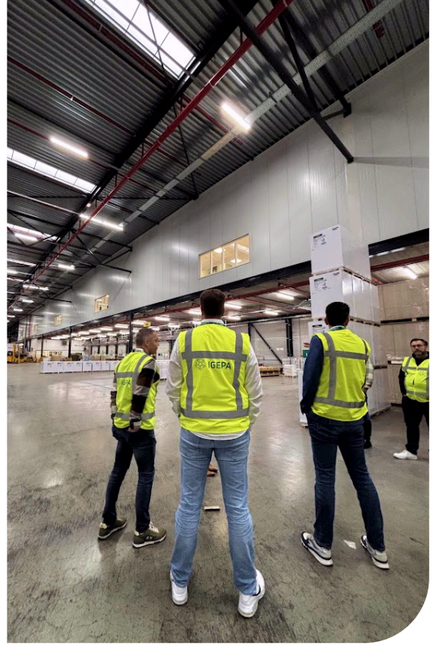


Figure 24. *Circular client day at IGEPA warehouse*

2.4.3 System map

To fully comprehend the complexities of transitioning to a circular economy, it is essential to first visualise the current state of the print and sign industry. The system map, Figure 25 on the following page, illustrates the complete lifecycle of a banner, tracking the flow of materials and information from initial production to end of life disposal.

By mapping the interactions between various stakeholders, from material producers and printers to consumers and waste collectors, this visualisation exposes the critical bottlenecks that currently prevent sustainable recovery practices.

Key insights from the system map:

- Material conflict:

The map traces how chemicals (such as terephthalic acid and ethylene glycol for PET and resin and plasticisers for PVC) are manufactured into banners via calendering, knife scraping or lamination. Consumers primarily choose these composites because they are cheap, durable and resistant to weather (UV, water and freezing).

- The lifespan disconnect:

A major systemic flaw highlighted in the map is the ratio of use-time to material durability. While the ultimate lifespan of the PVC/PET material can be up to 8 years, its average functional lifespan as a banner, at events or festivals, is merely 45 days.

- The linear lifecycle:

It becomes apparent that through the lack of a return system, the banners are doomed to follow a linear path towards incineration and landfills.

- The end of life bottleneck:

Once discarded, the vast majority of banners end up in landfills or are incinerated. Alternative recovery methods are currently negligible: less than 1% of the material is downcycled into items like clothing or gadgets.

- The circular opportunity:

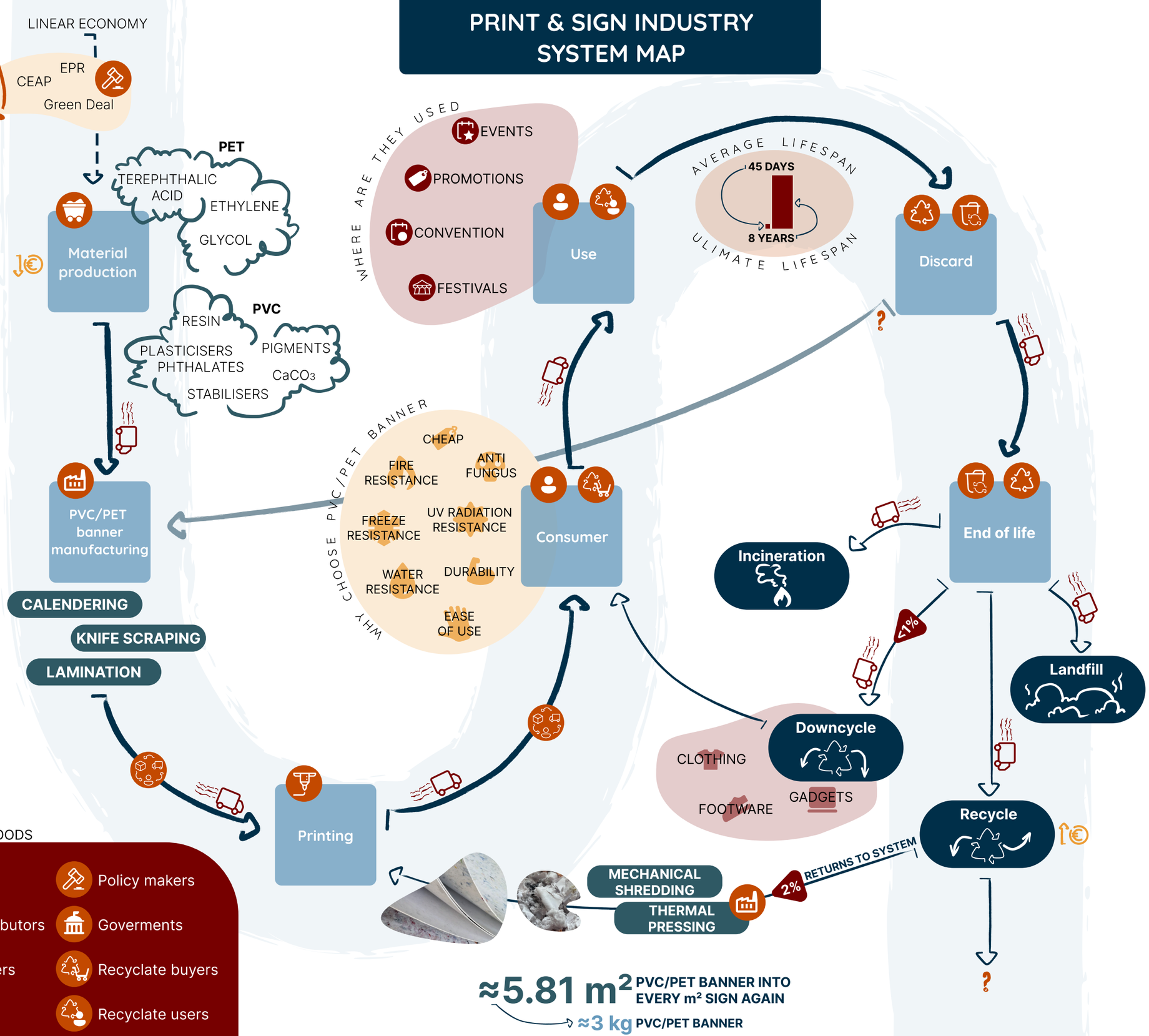
Only about 2% of the material successfully returns to the system through recycling. The map highlights the Sign Again process as a rare closed-loop pathway, illustrating that approximately 5.81 m² (or roughly 3 kg) of discarded banner is required to produce just 1 m² of new Sign Again paneling.

Ultimately, the overarching system context defines the core problem: the current industry operates in a highly fragmented manner. Stakeholders across the value chain do not work together effectively, thus the material loop has difficulty closing. This map serves as the baseline to identify where targeted interventions must be applied to disrupt this linear flow.

PRINT & SIGN INDUSTRY SYSTEM MAP

SYSTEM CONTEXT

Every year, millions of square meters of PVC/PET banners are manufactured for temporary advertising, only to be discarded after an average of just 45 days. Due to the PVC coating being permanently fused to a PET mesh, they cannot be separated, leaving landfilling or incineration as the default end-of-life. Instead of fighting the fusion, we can embrace it. By mechanically shredding and heat-pressing shredded banner waste, we transform this monstrous hybrid into repurposed composite panels. This process keeps materials in the loop for up to 7 cycles, capturing kilograms of waste.



TRANSPORTATION OF GOODS

- Material producers
- Virgin material distributors
- Banner manufacturers
- Printers
- Distributors
- Consumers
- Policy makers
- Goverments
- Recyclate buyers
- Recyclate users
- Recyclers
- Waste collectors

LEVERAGE POINTS

1. Procurement decisions, intervening at the consumers level
2. EPR implementation, forcing producers to fund a take-back system

LIMITATIONS

1. Thermal mismatch, PVC/PET composite is fused together
2. Price disparity, virgin material is cheaper than recycled

Figure 25. *Print and sign industry system map*

2.5 Circular principles

Having established the environmental severity of the current linear system, characterised by hazardous production and inadequate disposal (Sadroddini & Hosseini Khorram, 2025), it is crucial to explore the frameworks that can guide the industry toward sustainability. This section outlines the core principles of the Circular Economy and the R-Ladder, providing a theoretical basis for restructuring the print and sign value chain.

2.5.1 Circular economy

The print and sign sector is currently dominated by a linear 'take-make-use-dispose' model: raw materials are extracted, processed into short-lived products and then discarded. Integrating circular economy principles aims to decouple economic activity from the consumption of finite resources by designing waste out of the system.

According to Haffmans et al. (2018), circular business models focus on slowing, closing and narrowing resource loops to maintain product value for as long as possible. For the banner industry, this transition requires a systemic shift across four possible key areas:

1. Product as a Service (PaaS): Shifting from selling physical banners to leasing 'visibility'. Producers retain ownership of the materials, incentivising them to use durable, recyclable products that they can reclaim and process at the end of use.
2. Return and reuse logistics: Establishing infrastructure for the collection of banners after events, enabling them to be cleaned and redeployed rather than discarded.
3. Design for disassembly: Implementing modular or mono-material designs (such as removing metal grommets or using compatible coatings) to facilitate efficient recycling.
4. Standardisation: Adopting industry-wide standards for dimensions and materials to make large-scale collection and sorting economically viable.

By implementing some or all these changes the system could shift from the current linear to more circular one, the former visualised in Figure 21 and the latter as an aspiration for a nearby future system shown in Figure 26.

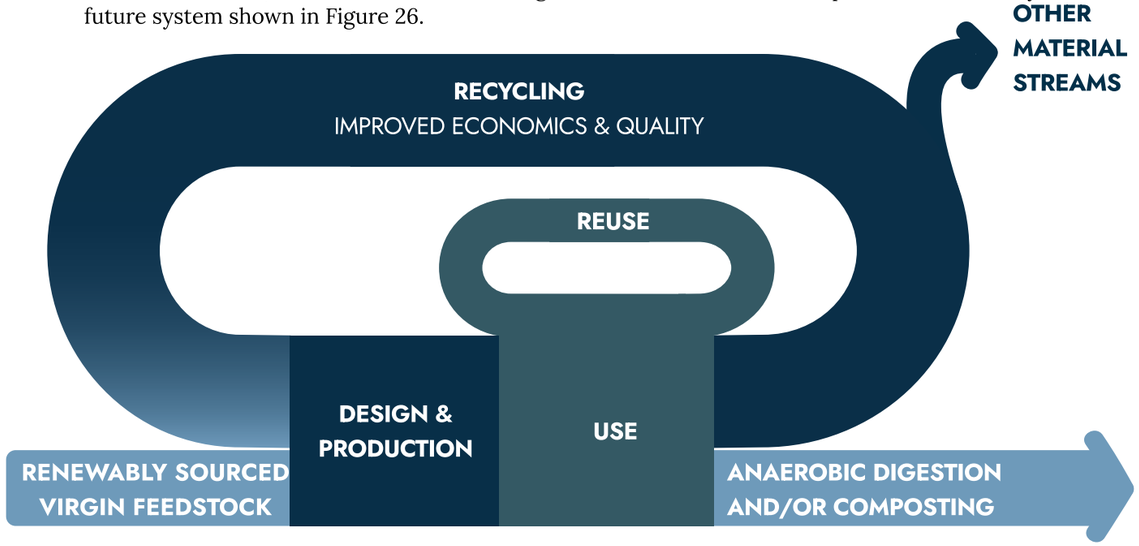


Figure 26. *Circular economy ideal to be achieved in nearby future inspired by Ellen McArthur Foundation, 2019)*

Implementing these models requires more than just technical innovation, it demands intense stakeholder cooperation and consumer awareness. Design decisions should be made at the start of the lifecycle which dictate the material's fate at the end. By adhering to important parameters for designing consumer products such as; low-impact materials, optimised lifespan, innovation and optimised end of life, the industry can transform from a source of pollution into a model for sustainable material management (Haffmans et al., 2018).

2.5.2 The R-Ladder applied

The R-Ladder provides a prioritised framework for circular strategies (Alivojvodic & Kokalj, 2024), ranking them from high value (negative environmental impact) to low value (positive environmental impact). Currently, the banner industry operates almost exclusively at the bottom of this ladder, relying on recover (incineration) or disposal in landfill. To move toward sustainability, the industry must prioritise higher-level interventions. Figure 27 visualises how value retention is maximised at the top of the hierarchy.

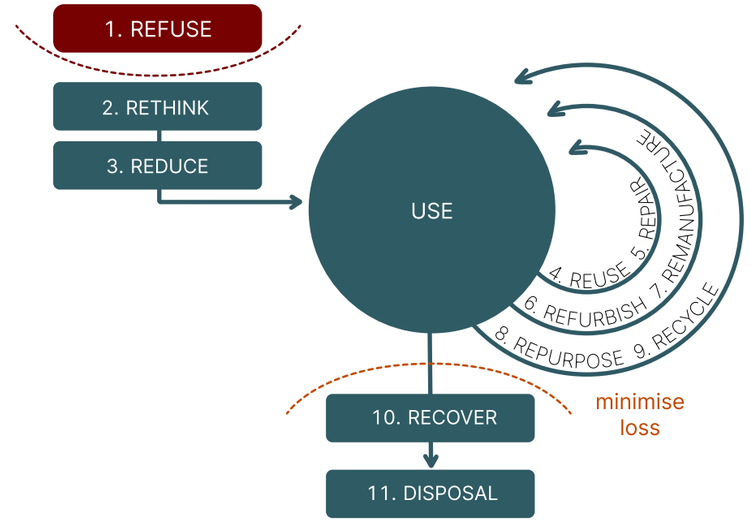


Figure 27. *Rethink: from size to value (Haffmans et al., 2018)*

Below is described what these steps could look like for the print and sign industry:

1. Refuse: The most effective strategy is to prevent waste entirely. This could involve choosing digital signage over physical prints for short-term events or questioning the necessity of a banner in the first place.
2. Rethink: Design modular systems for repeatable event signage or innovating the system to make product use more intensive.
3. Reduce: Optimising material usage and minimising printing waste.
4. Reuse: Designing generic, non-dated banners (e.g., "Sale" or "Welcome") that can be stored and reused for multiple campaigns rather than printed new each time.
5. Repair: Fixing minor damage to existing signage (e.g., patching tears, replacing broken grommets) to extend its functional lifespan.
6. Refurbish: Restoring existing signage systems to a high-quality state, such as updating only the printed textile while retaining the original hardware.
7. Remanufacture: Disassembling discarded signs and using their standardised components (like aluminum frames) to build brand new signage products.
8. Repurpose: Transforming end of life banners into new products with a different function, such as the bags or accessories mentioned in chapter 2.3.3.
9. Recycle: Processing waste materials into new raw materials. For this to work, the industry must move toward mono-materials (e.g. PET) to allow for high quality mechanical recovery. Another option is to innovate the chemical recycling method to be more econimivally viable.
10. Recover: The last resort before landfill. Incineration with energy recovery should only be used for materials that have become too degraded or contaminated for any other stream.
11. Disposal: Sending waste to a landfill with zero value recovery. This must be entirely evaded.

Transitioning up the R-ladder requires fundamental changes in the system and in people's mindset. This will reduce emissions, conserve resources and support new business models to align with circular economy principles.

2.6 Theoretical framework

Based on the extensive analysis of the material context, end of life challenges and systemic stakeholders conducted in the previous sections, a distinct set of barriers and enablers has emerged. To navigate this complexity, it is essential to structure these findings into a coherent model. This section presents the theoretical framework developed for this research (Figure 29), which maps out specific variables, the factors, into overarching categories, the domains. This structure serves as a diagnostic tool for designers to visualise where power lies within the system and defines the boundaries of the solution space for sustainable recovery practices.

2.6.1 Deriving domains

PVC banners, reinforced with PET, pose a severe environmental challenge. Their complex material composition, short use phase and limited recycling options create a persistent waste stream. PVC's chlorine content and PET's fossil-based origin together contribute to air pollution, greenhouse gas emissions and microplastic contamination. While incineration remains the most common disposal method, it destroys material value and releases toxic emissions. In contrast, reuse, repurposing and material substitution offer more circular alternatives. Achieving true sustainability will require systemic changes, redesigning products, rethinking business models and strengthening policies to close the loop on plastic signage.

The following framework is a result of the literature research and identifies which factors influence the overarching domains. Through this analysis, key challenges were clustered into seven distinct domains: Production process, Material, End of life, Economic, Systemic, Innovation and Environmental sustainability. As illustrated in the framework, these domains are interconnected and their specific underlying factors collectively define the boundaries of the solution space for sustainable recovery practices.



Figure 28. *Designing with Sign Again (Horizonteer, 2026)*

2.6.2 Proposed barrier framework

The proposed framework visualises the complexity of transitioning to a circular model by categorising barriers and enablers into specific domains.

The upstream domains of Production process and Material highlight the physical limitations of current banner technology. Key factors include the fusion of materials and the use of fossil fuel-based feedstocks, which inherently complicate recovery. The fused material nature of the composite, combined with necessary additives, results in a product that is not easily recyclable and for which there are limited alternative materials currently on the market with similar qualities. These material constraints directly impact the End of life domain, where a lack of specialised infrastructure forces the industry to rely on incineration or landfill rather than other recovery strategies.

The framework identifies Economic and Systemic factors as critical structural hurdles. Economically, the transition is hindered by the availability of low cost virgin material and high recycling costs, which make circular alternatives like Sign Again expensive in comparison. This is amplified by a lack of economic incentives to shift away from the current linear norm. Systemically, the industry suffers from stakeholder fragmentation and a dominant linear business model. A lack of policy enforcement further stalls the adoption of circular practices.

Finally, the domains of Innovation and Environmental sustainability represent both challenges and opportunities for the solution space. Innovation is currently constrained by a lack of funding, but offers pathways through material redesign and design for end of life or disassembly. Meanwhile, environmental factors such as high carbon footprint, harmful gas emissions and the short lifetime of banners drive the urgency for change, though low awareness remains a barrier to be addressed. Collectively addressing the factors within these seven domains is essential to reach the solution space and initiate sustainable recovery practices.

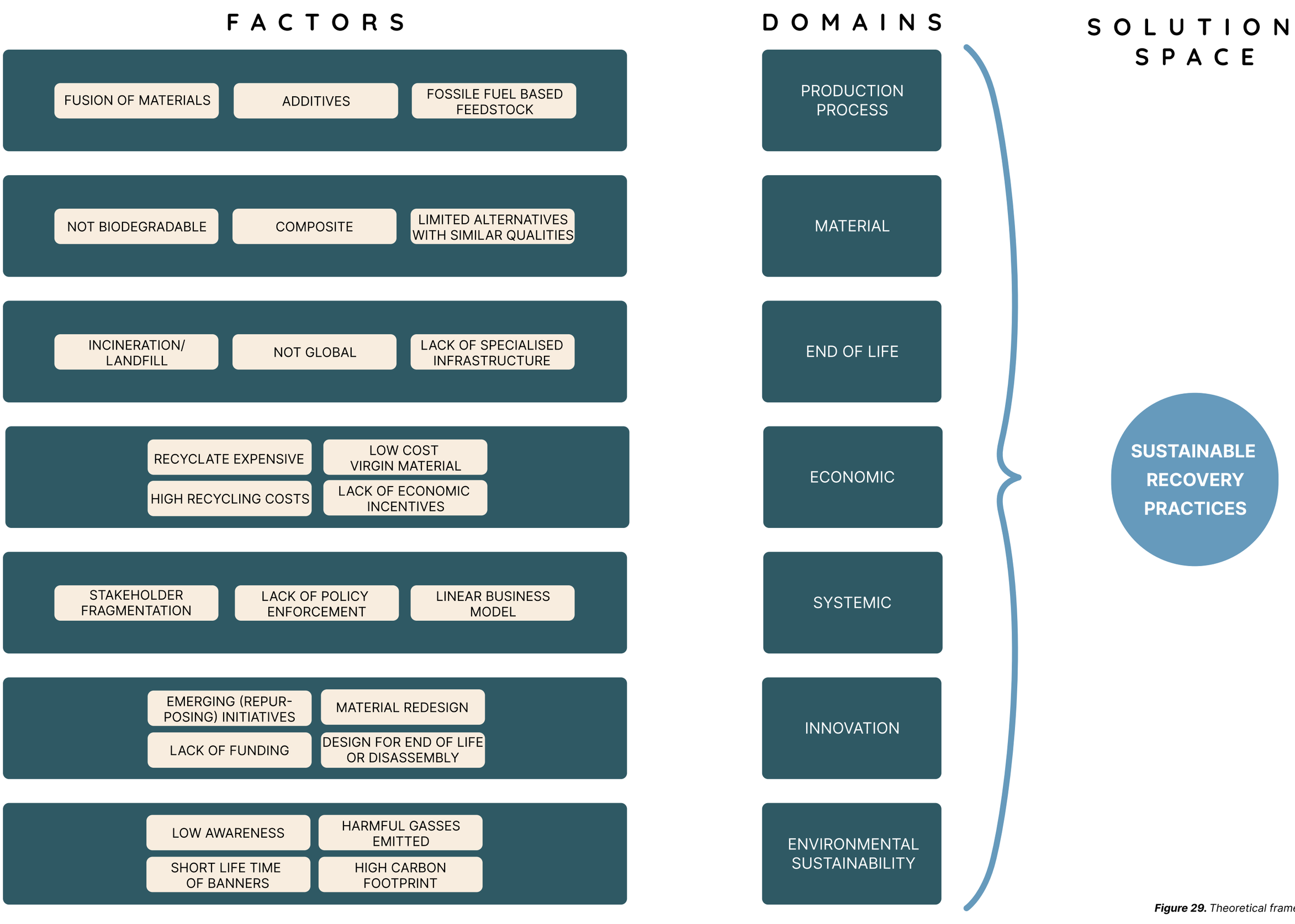


Figure 29. *Theoretical framework*

Chapter 3.

Research methodology

3.1 Sampling and stakeholders
3.2 Data collection and analysis

3. Research Methodology

This chapter outlines the research methodology employed to explore the transition toward a circular economy within the print and sign industry. Building upon the theoretical framework established in the literature review, empirical research was conducted to validate existing findings and uncover new, practical insights from active industry stakeholders. This chapter details the qualitative research design, the sampling strategy used to select participants, the data collection procedures and the analytical methods applied to interpret the findings.

To effectively address the central research question, this study utilised a qualitative research approach based on semi-structured interviews.

The decision to employ qualitative methods over a quantitative survey-based approach was driven by the inherent complexity of systemic transitions. Circular economy implementation in the print and sign industry is not merely a technical challenge; it is deeply intertwined with stakeholder behaviours, economic incentives and established supply chain norms. Qualitative research provides the necessary depth to explore these nuances, allowing the researcher to ask open ended questions concerning stakeholders' lived experiences and perceived barriers. It also offers the flexibility to probe deeper into unexpected answers, an opportunity absent in rigid quantitative questionnaires. At this exploratory stage of the thesis, capturing a diverse array of perspectives was valued to refining, validating and elaborating upon the initial theoretical framework.

The interviews were designed using a semi-structured format. This method ensures a degree of standardisation, allowing for structured comparison across different stakeholder groups, while maintaining the adaptability required to uncover less visible systemic factors. As Kallio et al. (2016) note, this careful balance of structure and flexibility significantly strengthens the validity and rigour of qualitative studies in applied design research.

The interview protocol was directly informed by the theoretical framework synthesised in Chapter 2. By systematically addressing the domains identified in the literature, the interviews served a dual purpose: validating the known factors influencing circularity and identifying undocumented variables currently shaping the industry. The complete interview protocol is provided in Appendix C.1. Furthermore, strict ethical guidelines were adhered to; the research setup was formally approved by the TU Delft Human Research Ethics Committee (HREC) (Appendix C.3) and informed consent was obtained from all participants prior to recording (Appendix C.2).

3.1 Sampling and stakeholders

A purposive sampling strategy was utilised to select participants who possess direct experience and expertise relevant to the lifecycle of PVC banners. The target demographics were initially identified through the stakeholder mapping and system analysis presented in Chapter 2.4.

To ensure a comprehensive and holistic understanding of the problem space, a total of 12 participants were selected. This sample size was deemed appropriate to reach data saturation regarding the core challenges of the industry. Participants were recruited through multiple avenues. Four interviewees were sourced through the professional network of the collaborative partner, Horizonteer. Two were acquired via peer recommendations and two academic experts were connected through the network of Delft University of Technology (TU Delft). The remaining four were identified independently during the literature review phase based on their published work or industry prominence. All initial contact and recruitment were conducted via email by the author.

To capture a holistic perspective that spans the technical, economic and systemic dimensions of the research question (feasibility, viability and desirability), the participants were categorised into four distinct stakeholder groups:

1. Recycling experts (N=3):

These participants were selected to provide grounded, technical insights into current recycling infrastructure. Their input was vital for understanding the mechanical and chemical constraints of processing hybrid materials like PVC banners, the realities of feedstock contamination and the technical feasibility of repurposing these polymers at scale.

Repurposing experts (N=4):

This group consisted of practitioners actively working with PVC banners as a secondary raw material or waste product. Their perspective illuminated the practical limitations, design constraints and market opportunities associated with transforming linear waste into new, functional products.

3. Producers and distributors (N=3):

Representing the traditional, linear core of the industry, these participants provided critical insights into supply chain logistics, material procurement and commercial viability. Their input was essential for assessing the economic barriers to adopting circular alternatives and understanding customer demand dynamics.

4. Sustainability and circular economy experts (N=2):

These individuals provided a macro-level perspective. Rather than focusing on daily operations, their interviews explored broader system level challenges, policy drivers (such as EPR) and the systemic enablers required to shift an entire industry toward circularity.



Figure 30. *Author taking notes (Horizonteer, 2026)*

3.2 Data collection and analysis

Data collection took place over a two month period during October and November 2025. The semi-structured interviews varied in length, typically lasting between 30 to 60 minutes, depending on the participant's depth of expertise and willingness to elaborate.

To accommodate the geographic distribution and availability of the participants, a mixed mode approach was utilised. Interviews were conducted in person when feasible, via online video conferencing platforms (e.g., Microsoft Teams) or over the telephone. Regardless of the medium, the standardised interview protocol was consistently applied. The questioning systematically touched upon all domains identified in the preliminary framework, prompting stakeholders to either confirm existing hypotheses or introduce new variables affecting their operations.

With explicit prior consent, all interviews were audio-recorded. This allowed the researcher to remain fully engaged in active listening and probing during the conversation, rather than focusing solely on note taking. Following each session, the audio recordings were transcribed verbatim to prepare the data for analysis.

The qualitative data generated from the interview transcripts was systematically evaluated using thematic content analysis. This approach provides a structured mechanism for identifying, analysing and reporting patterns (themes) within the data. The analytical process followed the established three-phase methodology outlined by Miles and Huberman (1994):

1. Initial coding:

The transcripts were thoroughly read and broken down into discrete, manageable units of meaning. A combination of deductive and inductive coding was employed. Deductive codes, derived pre-emptively from the literature review framework, were applied to recognise expected patterns (e.g., cost barriers, material contamination). Simultaneously, inductive coding was utilised to capture emergent, unforeseen data points directly from the participants' original statements.

2. Category development:

In the second phase, the extensive list of initial codes was reviewed and clustered into broader categories based on thematic similarities and relationships. For example, specific codes relating to machinery limitations and chemical separation difficulties were grouped under the category of ‘technical material limitations’.

3. Theme identification:

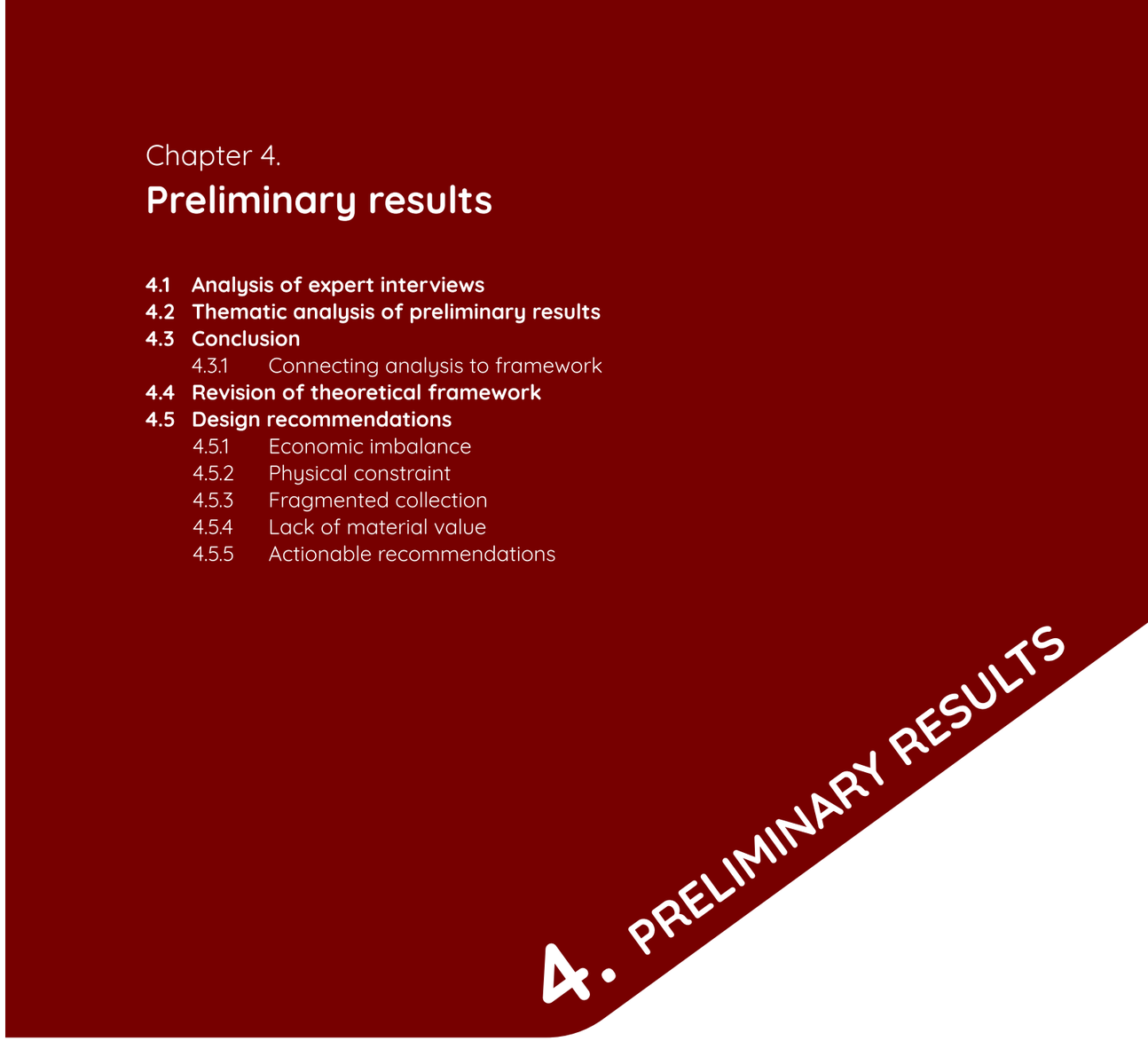
Finally, these categories were synthesised into overarching themes. These themes represent the core systemic insights and fundamental leverage points required for circular innovation within the print and sign industry.

By employing this structured analytical framework, the raw qualitative data was translated into the refined framework and actionable design recommendations presented in Chapter 4.

Chapter 4.

Preliminary results

4.1 Analysis of expert interviews
4.2 Thematic analysis of preliminary results
4.3 Conclusion
4.3.1 Connecting analysis to framework
4.4 Revision of theoretical framework
4.5 Design recommendations
4.5.1 Economic imbalance
4.5.2 Physical constraint
4.5.3 Fragmented collection
4.5.4 Lack of material value
4.5.5 Actionable recommendations



4. Preliminary Results

This chapter entails the findings of 12 interviews with experts within the system, the interviews were conducted to gain a holistic perspective of the challenges within the print and sign industry. The analysis should also give insight on how the theoretical framework reflects the limitations of the system and where factors might be missing to get a more complete picture. The chapter is structured per domain where the results and implications for the framework and the overall industry are explained in depth.

4.1 Analysis of expert interviews

All interviews were conducted with the same question list, see Appendix C.1. After transcribing the 12 interviews, they were broken down into key statements, formulated into factors and then classified into the relevant domain. The factors found in the framework were checked and further validated on their relevance. Besides this, newly identified factors mentioned by at least half the interviewees were to be added to the existing framework. This is because the interviewees possess practical expertise within the current system and understand the challenges involved in real world scenarios. In Table 2 an overview can be found of the existing factors and how often they were mentioned and validated across the 12 interviews.

Table 2 *Total mentions per factor of each domain*

Domain	Factor	Total mentions
Production process	Fusion of materials	7
	Additives	6
	Fossil fuel based feedstock	2
	Total	*15*
Material	Non-biodegradable	5
	Composite	5
	Limited alternatives with similar qualities	5
	Total	*15*
End of life	Incineration/landfill	8
	Not global	2
	Lack of specialised infrastructure	7
	Total	*17*
Economic	Recyclate expensive	3
	Low cost virgin material	8
	High recycling cost	9
	Lack of economic incentives	7
	Total	*27*
Systemic	Stakeholder fragmentation	5
	Lack of policy enforcement	8
	Linear business model	8
	Total	*21*
Innovation	Emerging initiatives	5
	Lack of funding	4
	Design for end of life or disassembly	3
	Material redesign	5
	Total	*17*
Environmental sustainability	Low awareness	6
	Harmful gasses	1
	Short life time	5
	High carbon footprint	5
	Total	*17*

The newly mentioned factors described in this chapter were all mentioned by at least 2 interviewees. Even though some factors are not mentioned by more than half the interviewees they were, however, important enough to be mentioned by different stakeholders. This is why they are discussed and should be kept in mind. The factors referred to by half or more and thus significant enough to add to the revision of the theoretical framework can be found in Table 3.

Table 3. *Total mentions per new found factor mentioned by more than half of the interviewees*

Domain	Factor	Total mentions
End of life	Lack of return or take-back system	8
	Policy gaps	9
Economic	Market collapse	7
	Consumer behaviour	7
	Marketing/communication challenges	8
	Recycled materials remain in stock	6
Systemic	Logistic and collection challenges	7
Innovation	Innovative collaboration	6
Environmental sustainability	Transparency and storytelling	6
	Recognise the value of materials	6

A new factor in the Production process domain was mentioned twice. The energy and labour costs are high in Western Europe, this makes large scale recycling less attractive than buying new materials from countries with lower production costs.

In the Material domain there was also one new factor mentioned by the interviewees. The contamination in PVC banner waste (mentioned 3 times) complicates the processing and downgrades recycled quality. This includes dirt, ink, metal rings and coatings.

Two new factors came to light in the End of life domain. The lack of return or take-back systems was mentioned 8 times. Now most banners are discarded or incinerated rather than collected for reuse. Second are the policy gaps (mentioned 9 times), there is no end of life responsibility allocations for banners. Both are mentioned by more than half of the total interviewees and wil make the framework more complete.

The Economy domain had found four new factors to be added to the framework. Firstly, the market collapse (since 2023) was mentioned 7 times. Over 700,000 tons of recycling capacity lost in Europe due to uncompetitive prices. Next, the consumer behaviour was mentioned 7 times. Clients prioritise price over sustainability unless subsidies or regulations intervene. Thirdly there are marketing and communication challenges. this was mentioned 8 times. Companies are having difficulty telling the green story and selling this to consumers. Lastly, 6 interviewees said that recycled material remains in stock. There is currently a limited market for recycled materials and companies are forced to sell below cost price.

In the Systemic domain one new factor was found and mentioned 7 times. Challenges in transportation, storage and lack of organised collection systems for post-consumer PVC banner waste can make it difficult to set up a circular system.

The need for innovative collaboration within the Innovation domain was mentioned 6 times. They suggested a need for co-design among printers, recyclers and manufacturers.

Three new factors were highlighted in the Environmental sustainability domain. Social inclusion was mentioned by 3 interviewees. Repurposing workshops integrate people distant from the labour market, combining environmental and social sustainability. Transparency and storytelling was brought up by 6 different people. They said that making the circular narratives more visible (e.g., product tags, façades) can increase public engagement. Lastly, 6 experts mentioned the lack of recognition for the value of materials. Consumers treat plastics like a throw away product due to ‘set in stone’ behaviour, yet plastics were initially introduced to lighten the load for the raw materials of the earth. It is backwards to then treat these materials like they are infinite.

4.2 Thematic analysis of preliminary results

Through the 12 interviews the framework was tested in practice. The results of the interview analysis for the existing factors show that they were all mentioned at least once. This means that the framework is substantially sound and reflects the perspectives of the experts and stakeholders in the industry. The remainder of the chapter will explore the results per domain and their implications.

Along with the material domain, the production process domain yielded the fewest mentioned factors, totaling 15. However, the 'fusion of materials' (mentioned by 7 participants) emerged as a primary barrier, confirming it as a major practical challenge for both manufacturers and recyclers. As one recycling expert explained: : “This [a PVC banner] is often a canvas made of PVC with fibre reinforcement and for recycling, that is actually a very, very difficult to poorly recyclable stream”. They emphasised the severity of this issue, stating: “If you cannot separate the fibres from the PVC, there is basically no possibility for recycling”. Another expert corroborated this, noting that the primary issue with standard banners, such as Banner 510 (named after its weight 510g/m² (Probo, 2025a)), is that the PVC and PET materials are “completely fused, making it very difficult to recycle”. Another factor within the production process domain, additives, was also highlighted by half of the interviewees (n=6). A third recycling expert expressed concerns regarding the unknown chemical composition of imported materials: “There are very many cheap Chinese banners. What plasticisers are added to those? No idea, you really have no idea”. Notably, no new factors were identified within this domain, nor in the material domain, by a majority of the participants.

The domains of End of life, Innovation and Environmental sustainability each received a total of 17 mentions. Within the End of life domain, two factors were cited by more than half of the participants: incineration/landfill (mentioned 8 times) and lack of specialised infrastructure (mentioned 7 times). An expert repurposer shared their perspective on the fate of non-biodegradable materials, stating, “Most of it is still usable, there are big bins outside the venues that people just throw all this stuff into. It's heartbreaking.” Interviewees also had thoughts to share regarding the lack of specialised infrastructure. One of the circularity experts shared why these infrastructures struggle to exist: “I know that three high quality recycling factories started, maybe 4 last year in the Netherlands, went bankrupt because they cannot compete [with cheap virgin materials].”



Figure 31. *Repurposing at Pretty plastic (Pretty Plastic & Van Apeldoorn, 2025)*

Two important new factors were also identified within the End of life domain: the lack of a return or take-back system and policy gaps. A company that repurposes pure PVC waste into building materials shared their thoughts on the former: “The main barriers to scaling up are logistical: the collection, sorting and quality control of post-consumer waste.” Conversely, a printing company in the sign industry feels it is not their responsibility to organise such systems, arguing: “Look, ultimately we sell those banners, so subsequently it is up to our client what they do with them.” Regarding policy gaps, a circularity expert mentioned: “We don't have a government that has a long-term vision, that support isn't there right now.” A recycling expert echoed this sentiment: “There definitely needs to be support from governments and a levy on the input of new virgin plastics. As long as that isn't there, it is very difficult for companies.”

In the Innovation domain, no existing factors were raised by a majority of the participants, however, a new factor was identified in which half of the interviewees expressed a need for collaborative innovation. A recycler stated: “The stakeholders need to sit around the table together to improve the product design, making it mechanically better [recyclable].” An repurposer expressed similar thoughts, noting: "Circularity requires collaboration across the value chain, not just at the recycling stage."

Finally, concerning Environmental sustainability, low awareness was mentioned by six interviewees as a barrier to a circular system. One repurposing expert noted, “Every company does its own thing and is completely unaware that you can actually do things with the waste,” while another added, “I don't think enough people realise the volume of waste that comes from doing these events. You just don't even think it's a job [the recycling of PVC banner waste] until you're in it.” A printing company observed that despite some awareness, “It often becomes a budget thing.” Two new factors were found in this domain: transparency and storytelling and the recognition of material value. As a repurposing company explained: “Architects and clients are increasingly aware of material provenance and are looking for visible circular stories in their façades.” However, consumer recognition of value remains low, as a circular expert summarised: “Actually, you lose all value after that [incineration], right? With banners too, it is worth zero, even negative considering what you have to pay to dispose of it.”

The Systemic domain (21 mentions) is the second most frequently mentioned barrier in the system, as mentioned by the interviewees. Two existing factors were mentioned 8 times throughout the 12 interviews: the lack of policy enforcement and the current linear business model. Enforcement challenges mentioned by a recycling expert: “Small volumes disappear, simply in the residual waste bin. When it comes to larger volumes, that’s when it really becomes apparent.” The linear business model is standing in the way and an other recycling expert explains why: “This is when people always choose for the cheapest option.” And a repurposing expert says: “I can't stand it when I go around a show and I see that someone has printed the date on something. It is instantly only used for that one time.” The new factor mentioned 7 times is that there are logistical challenges which influence the possibility for collection, transportation and storage. One of the circular experts enlightens: “That return stream is very varied material, also in terms of dimensions. Try getting that all in one place.” and a repurposing experts mentions this: “I think collecting, storing, sorting... it has to be transported somewhere to be processed? Well, that is the barrier.”

The Economic domain, with 27 mentions, is the most frequently cited limitation within the current system. Three specific factors were cited by more than half of the interviewees. The low cost of virgin material was mentioned eight times, eliciting strong opinions from interviewees. As one recycling expert explained, “That stems from new plastic, virgin plastic, it is far too cheap,” adding that consequently, “our recycled materials are too expensive, so [they are] not interesting”. A printing company clarified why these prices remain so low: “Standard PVC is used all over the world, a lot of competition means competition in price and thus lower prices”.

Conversely, recycling costs are high. This factor was explained by a recycler who noted that “Europe as a production country is actually much too expensive,” implying that processing local waste is costly compared to global production standards. A repurposing expert added, “It naturally costs money to have something made from it. It costs them [close to] nothing to have it incinerated”. Another expert concurred, noting, “It is not cheap, especially when you compare it to the cost of a skip [landfill]”. An experienced recycler pointed out another technical economic barrier: “This process [chemical recycling] is very expensive and is actually only interesting when you have enough PVC powder left over. With banners, that is never the case”. The final factor raised by the majority in this domain was the lack of incentives. As one recycler stated, “As long as that isn't there, as long as it remains 'a free market,' it is very difficult for companies”.

Additionally, four new factors were identified within the Economic domain. First is the collapse of the recycled material market. A recycler explained, “Recycling worldwide has been in a very deep valley for over two years, 700,000 tons of recycling capacity has disappeared”. Second, consumer behaviour heavily impacts the system's ability to change, as clients continue to purchase banners for short-term use. This was supported by a printing company, who noted that banners are “sometimes [used for] just one single night”.

The third new factor is the struggle marketing faces in drawing attention to sustainable alternatives, which is partly a communication challenge. A repurposer noted, “It's more the story behind it that they can then sell on to their customers. So yeah, it's difficult to try and get them to understand that”. A circularity expert compared this to RetourMatras, a company selling recycled mattresses (RetourMatras, 2025): “When they sold it as a highly ventilating mattress, it suddenly sold super well, even though the mattress was the same [as mattresses made from virgin materials]. So maybe the sustainable story doesn't need to be in the foreground”. Finally, there is the challenge that recycled materials often remain in stock. As one repurposer shared, “We are creating stock that we don't know if there is a market for”.



Figure 32. *Repurposing at Stichting Stunt (Stichting Stunt, 2024)*

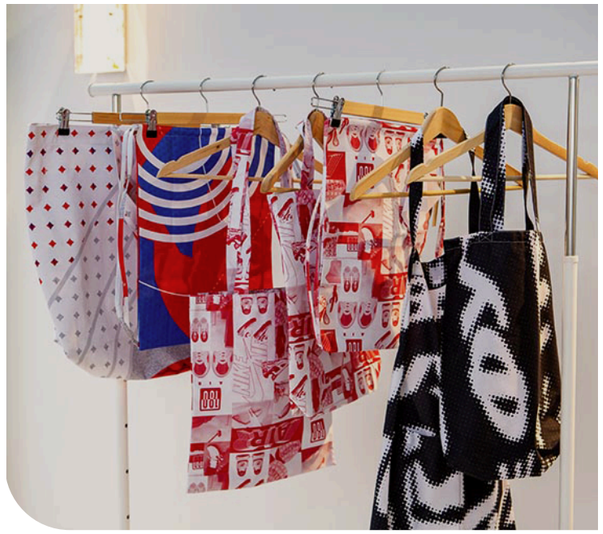


Figure 33. *Repurposing at Re-banner (Re-banner, 2025)*

4.3 Conclusion

The analysis of twelve expert interviews confirms that the theoretical framework developed in this study possesses a high degree of validity. Every factor originally identified through the literature review was recognised and confirmed by experts in the field. However, the empirical data nuances this picture by revealing a distinct hierarchy of urgency and uncovering ten new, critical factors that were missing in the initial framework.

The most significant finding is that the primary bottlenecks for sustainable recovery practices are not technical or material, but fundamentally economic and systemic. The Economic (27 mentions) and Systemic (21 mentions) domains emerged as the most dominant. Specifically, high recycling costs (9 mentions), low virgin material costs (8 mentions) and a lack of incentives (7 mentions) were cited most frequently. This indicates that while structural and economic conditions form the largest blockades, technical and material factors play a role but serve more as boundary conditions than primary obstacles. Such obstacles are fusion of materials (7 mentions) and additives (6 mentions). Essentially, while technical recyclability remains a challenge, the lack of a viable business case and policy drivers constitutes the actual bottleneck.

Innovation and the End of life domain (both 17 mentions) highlights a need for better infrastructure, specifically pointing to incineration/landfill (8 mentions) and lack of infrastructure (7 mentions) as major issues. This confirms that the absence of an efficient, scalable and internationally aligned end of life infrastructure hinders circular solutions. Meanwhile, Innovation and Environmental sustainability (both 17 mentions) are acknowledged by stakeholders as important but are viewed less as urgent problem sources and more as necessary facilitators for the future. The urgency lies in the economic incentives and systemic structures.

Beyond validating existing factors, the interviews brought ten new factors to light that are structurally relevant (mentioned 6–9 times). These additions reveal four dimensions that were underrepresented in the original framework:

- Operational logistics:

While the theoretical framework addressed infrastructure, practice highlights the specific absence of return or take-back systems (8 mentions). Without effective reverse logistics, circularity cannot exist.

- Policy gaps:

Literature focused on enforcement, but experts identify policy gaps (9 mentions) as the greater obstacle, pointing to fragmented regulations that fail to support circular ambitions.

- Market dynamics and behaviour:

A crucial new insight is the socio-economic dimension. Factors such as market collapse (7 mentions), consumer behaviour (7 mentions) and unsold recycled stock (6 mentions) demonstrate that the market often fails to absorb materials even when recycling is technically successful.

- Cultural values:

Finally, factors like transparency and storytelling (6 mentions) and collaborative innovation (6 mentions) emerged as essential enablers for building awareness, trust and redefining the intrinsic value of waste materials.



Figure 34. *Circular client day at IGEPA*

4.3.1 Connecting analysis to framework

The juxtaposition of the interview results with the initial theoretical framework offers three key insights that define the contribution of this study: theoretical validation, hierarchical urgency and necessary extensions.

The analysis confirms the structural validity of the initial framework. All factors identified in the literature review were explicitly recognised by the interviewees as relevant in practice. This implies that the categorisation of domains captures the challenges within the PVC banner recovery system. The framework provides a correct view of the barriers present

However, the frequency analysis suggests that the framework should not be viewed as a flat list of equal domains. The significant disparity in mentions, with Economic (27) and Systemic (21) factors far outweighing Material (15) or Production process (15) factors, indicates a necessary shift in perspective. The framework effectively describes the technical constraints (Material/Production process/End of life), but the drivers of failure are situated in the Economic and Systemic domains. Consequently, the framework should be reinterpreted hierarchically: Economic and Systemic factors constitute the dominant, overarching barriers that dictate the viability of the system, while technical factors manifest as secondary challenges within those constraints. Innovation and Environmental sustainability function primarily as facilitators rather than barriers, as they contain factors which enable a circular system instead of limiting it.

Finally, the identification of ten new factors highlights specific gaps where the theoretical framework requires extension to align more with reality. The End of life domain must be expanded to include reverse logistics. It is not merely about the existence of recycling facilities (infrastructure), but the operational mechanisms (take-back systems) to get materials there. The Systemic domain requires a nuance. The barrier is not just weak enforcement of rules, but the substance of the policies themselves (policy gaps), which are often fragmented or non-existent. The original framework also lacked a dedicated market and behaviour dimension. The findings regarding consumer behaviour, market collapse and the stockpiling of recyclates suggest that expansions are needed to capture the demand barriers. The strong emergence of transparency, storytelling and value recognition suggests that the Environmental sustainability domain should be broadened to include cultural and behavioural enablers.

In conclusion, while the initial framework provides a solid foundation, the empirical analysis dictates that it should be evolved into a more dynamic model. This evolved model must prioritise economic and systemic drivers and secondly incorporate the operational, behavioural and cultural dimensions of the circular transition.

4.4 Revision of theoretical framework

The results of the qualitative interviews gave insights into the perspectives of stakeholders within the value chain. By adding their most mentioned factors and the relevance of each domain in the framework it transforms from a theoretical framework to an applied framework. On the following page the revised framework can be found (Figure 36), it includes the new found factors and a better visualisation of how large the affect is of each domain. The reasoning of how relevant each domain is within the system can be found in Table 4. Here the dominance of the domains are expressed in percentages based on how often factors within a domain were mentioned across the interviews.

Table 4. *Total mentions per domain and their relevance in percentages*

	Total mentions per domain				
Domain	Existing factors	New factors	Total mentions	Percentage (%)	
Production process	15	0	15	7.89	≈ 8.0
Material	15	0	15	7.89	≈ 8.0
End of life	17	8	25	13.16	≈ 13.0
Economic	27	28	*55*	28.95	≈ 29.0
Systemic	21	7	*28*	14.74	≈ 15.0
Innovation	17	6	23	12.11	≈ 12.0
Environmental sustainability	17	12	29	15.26	≈ 15.0
Total	129	61	190	100	

The new framework now clearly visualises which domains exert the most power on the system and how they constrain it in the transition towards circularity. In this model, Economic and Systemic factors act as the primary rigid barriers. Production, Material and End of life factors function as secondary dependent barriers. Lastly, Innovation and Environmental sustainability act as facilitators.

Through Figure 35, this dynamic is illustrated using an analogy. The 'room' represents the current linear operational space of the industry, banners are made with certain materials and have a set in stone end of life. The 'ceiling' represents the Systemic barriers, policies, lack of legislation and rigid industry standards pressing down and restricting growth. The 'floor' represents the Economic barriers, dictating the financial reality that no change can occur if it is not economically viable. The system is trapped between these two forces. To break out of these boundaries, the system requires Innovation and Environmental sustainability, which act as the 'doors' or 'tools' necessary to push back the ceiling and reinforce the floor, allowing the system to expand into a circular model.

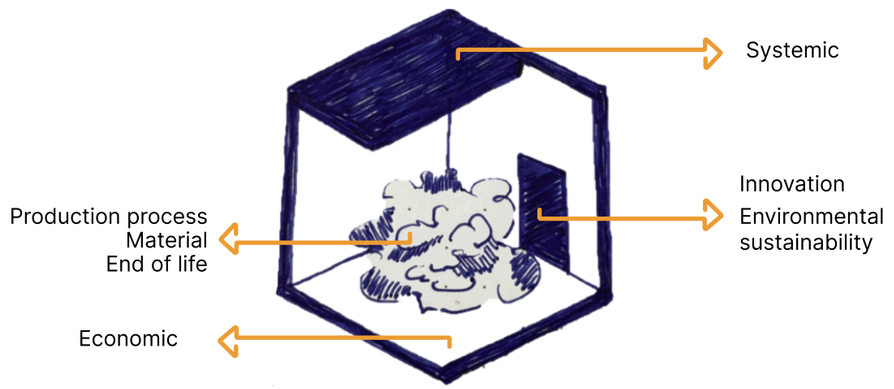


Figure 35. *Illustration of how the domains act as boundaries and facilitators through an analogy*

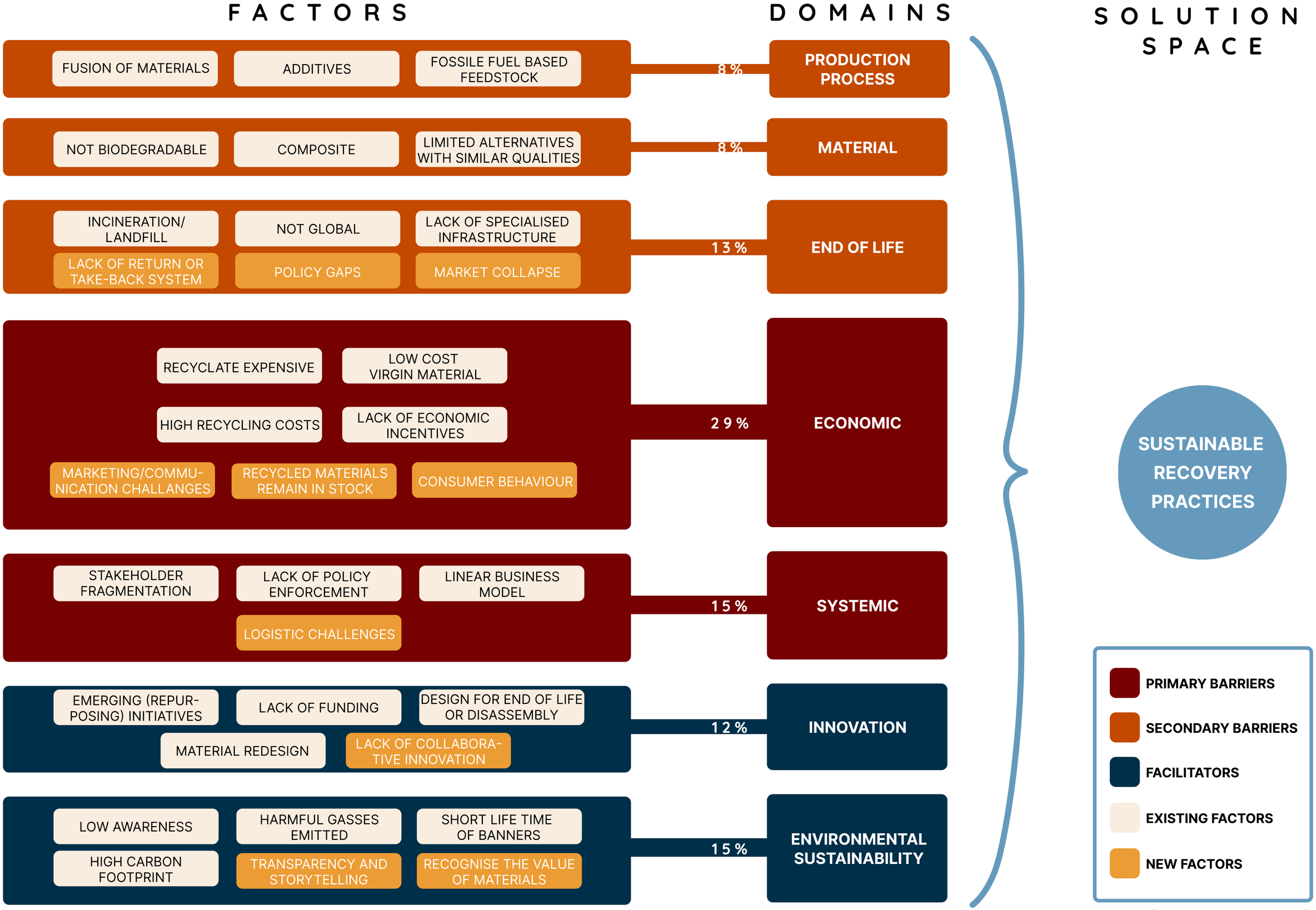


Figure 36. *Revised theoretical framework*

4.5 Design recommendations

Based on the analysis of the expert interviews and the subsequent edit of the theoretical framework, it is evident that a purely technical solution is insufficient to solve the banner waste problem. To formulate effective design interventions, it is necessary to prioritise the barriers identified during the thematic analysis. While all domains present challenges, the interview data indicates that certain structural barriers have a disproportionate impact on the system's ability to transition. Understanding why these specific barriers are the most restrictive is foundational for developing the resulting design recommendations.

4.5.1 Economic imbalance

The economic disparity between inexpensive virgin PVC and the high cost of local recycling is the primary driver of the linear system because it dictates market behaviour. Without environmental taxation or EPR fees, sustainable alternatives cannot compete on price. Because financial margins in the sign industry are tight, print companies and end-clients default to the cheapest option. This indicates that any design intervention cannot rely solely on the environmental goodwill of the client; it must either offer a functional advantage or be embedded in a business model that offsets the initial material cost.

4.5.2 Physical constraint

The permanent fusion of the PVC coating and the PET mesh is a fundamental barrier because it physically prevents traditional mechanical recycling. Even if collection logistics and economic incentives were resolved, the material itself cannot be separated into pure streams. This makes the existing waste stream a dead end for conventional recycling facilities. Consequently, design recommendations cannot focus on separating these polymers. Instead, interventions must focus on utilising the composite as a whole; embracing the heavy, rigid properties of the mechanically pressed shreds.

4.5.3 Fragmented collection

The lack of a structured take-back system halts the circular loop before it can begin. Banners are distributed across highly fragmented locations such as individual events, construction sites and retail stores, in varied sizes and conditions. Because end-users view the banners as disposable, organising reverse logistics to collect, sort and transport this bulky material back to a central processor is expensive. A successful design intervention must address the logistical chain directly, perhaps through regional take-back schemes or formal leasing contracts, rather than focusing solely on material innovation.

4.5.4 Lack of material value

Finally, the systemic lack of recognition for material value shapes the industry's operational mindset. Consumers and designers currently treat banners as short-term, throwaway items, frequently printing specific dates or temporary event names on them that instantly render the material obsolete after a single use. This behaviour suppresses the market demand for durable, circular alternatives. To counter this, a design intervention must tackle the behavioural barrier through transparent storytelling, shifting the product offering away from single-use consumables toward reusable applications.

4.5.5 Actionable recommendations

Based on the mechanics of these structural barriers, the following specific design recommendations have been formulated to guide the ideation phase and the development of the final concept:

Make the circular story visible and actionable
To overcome the adoption barrier driven by low consumer awareness, the primary design recommendation is to develop an intervention that translates environmental data, material provenance and technical properties into transparent, accessible storytelling. By doing so, designers can help justify the higher cost of recycled materials and lower the threshold for adoption.

Embed products within a service model
Because the lack of return systems and logistical challenges act as structural limits, future design interventions should not treat repurposed materials simply as static objects to be sold. Instead, they can be embedded within a service model (e.g., leasing modular event flooring or reusable signage) where reverse logistics are integrated into the value proposition. The design challenge lies in communicating the value of this service to clients who are accustomed to linear purchasing.

Embrace the material's properties
While upstream design should eventually transition to mono-materials (e.g., 100% PET), the immediate reality is an influx of fused PVC/PET banner waste. Because the fusion of materials makes complete materials separation unviable, design interventions must leverage the heavy, rigid and weather-resistant nature of Sign Again for applications where weight and durability are assets, rather than attempting to force the recyclate back into flexible banner applications.

Create a boundary object
Stakeholders emphasised that parties need to collaborate to improve circularity. Moving away from isolated in-house development requires tools that foster co-creation between printers, recyclers and end-clients. A design intervention must serve as a boundary object, a shared communication tool that allows different stakeholders to understand the systems limitations and align on circular standards early in the procurement phase.

Chapter 5.

Design methodology

5.1 Design methodologies
- 5.1.1 Discover
- 5.1.2 Define
- 5.1.2.1 Problem mapping
- 5.1.2.2 PoR strategic roadmap
- 5.1.2.3 PoR concept
- 5.1.3 Develop
- 5.1.4 Deliver

5. DESIGN METHODOLOGY

5. Design methodology

This chapter describes the design process from start to finish, explaining how the project transitioned from qualitative and quantitative exploration to tangible design interventions. The methodology provided a structure to navigate the complex challenge of material adoption, from identifying the physical limitations of the recycled composite to designing and validating systemic solutions. This chapter aims to clarify the steps taken to reach the final strategic and conceptual design results.

5.1 Design methodologies

The research follows the design thinking process of the double diamond in combination with IDEO's 3-stage framework. Together the two frameworks give an accurate view of how the project took shape over time and what steps had to be taken to come to a solution and implementation.

The research process followed the Double Diamond design thinking model in combination with IDEO's three-stage framework. Using both approaches provided a more detailed plan during the process, from initial problem exploration to solution development and implementation.

The Double Diamond model highlights the divergent and convergent ways of thinking that occur during design, structured across four phases (Design Council, 2005), see Figure 37:

- Discover: Initial insights are gathered, usually beginning with identifying user needs or an observed problem area.
- Define: User needs are interpreted and aligned with strategic or business objectives, narrowing the focus.
- Develop: Possible solutions are generated, iterated and tested through design methods.
- Deliver: The final concept is refined, validated and prepared for launch or implementation.

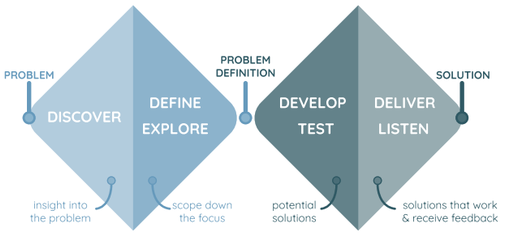


Figure 37. *Double diamond framework*
(Design Council, 2005)

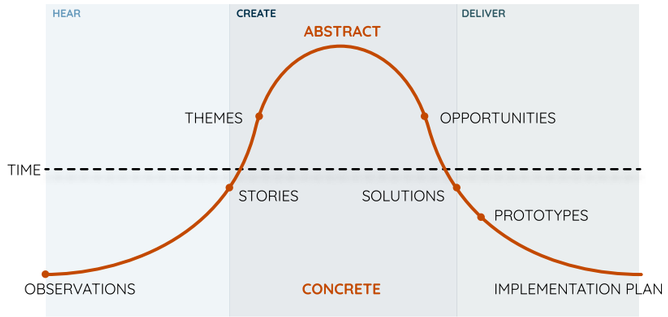


Figure 38. *IDEO's 3 stage framework*
(Design Council, 2005)

IDEO's Human Centered Design (HCD) framework was initially developed for social innovation projects, particularly those in low resource contexts (Design Council, 2005). Its terminology is simplified and memorable and the stages emphasise challenges typical in community based environments. Although the framework was designed for developing countries, it can also be adapted to other project domains, including the present research. The abstraction process, prototyping and implementation steps help deliver a product that has resonance with the customer says Gaubinger et al. (2015), see Figure 38. The three stages of the framework are:

- Hear: Builds an empathic understanding of users and clarifies the problem to be solved. This stage establishes contextual awareness, reveals user perspectives and supports reframing the design challenge.
- Create: Encourages experimentation, co-creation and prototyping. Similar to ideation and prototyping in other design processes, this stage helps identify opportunities while validating assumptions in collaboration with those directly affected by the problem.
- Deliver: Focuses on implementation and logistics. This stage ensures concepts can be integrated within the target context, overcoming practical barriers and supporting sustainable implementation.

IDEO's framework is particularly complementary to the Double Diamond model (see Figure 39), as it provides greater depth to the otherwise high-level structure of divergent and convergent thinking (Design Council, 2005; IDEO, n.d.). While the Double Diamond offers a clear structure to the process, it remains relatively abstract in terms of methods and user engagement. IDEO's stages address this gap by prioritising empathic inquiry, co-creation and context specific implementation. Integrating the two frameworks therefore enhances methodological foundation, the former establishes a coherent sequence of design phases, while the latter introduces concrete activities and considerations that support human centred decision making throughout. Using both models in tandem ensures that the design process is structured yet responsive to stakeholder needs and real world constraints, offering a richer and more reliable approach than relying on the Double Diamond alone.

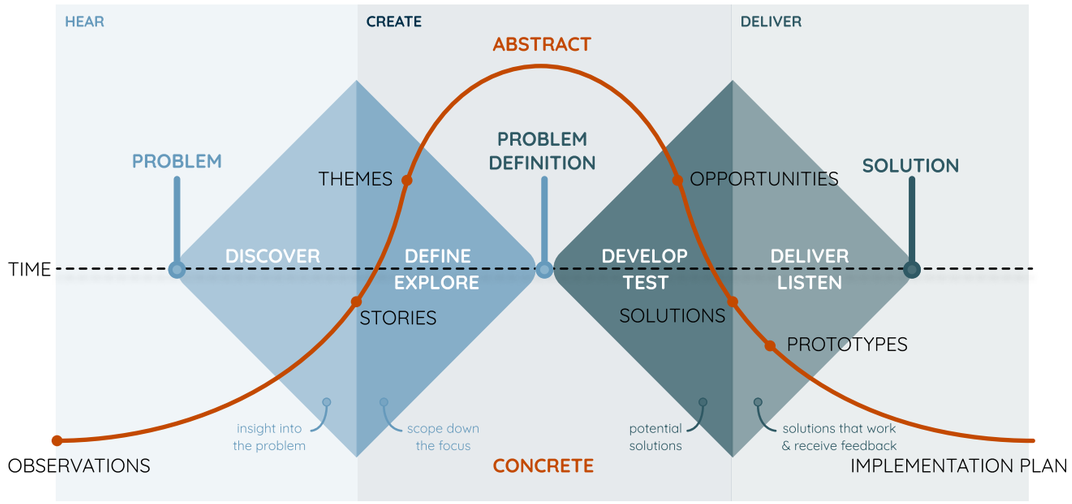


Figure 39. *Design methodologies combined*

The combined use of the double diamond and IDEO's frameworks structured the design process into a series of phased and interrelated activities moving from problem exploration to implementation.

5.1.1 Discover

In the Discover/Hear phase, the project began by gathering extensive, hands-on contextual knowledge. Rather than starting with theoretical assumptions, the Discover phase was driven by two primary activities: understanding the systemic barriers through co-creation sessions and exploring the physical constraints of the material.

Co-creation sessions were held with stakeholders. The objective was to gain concrete insights into the trends, concepts and visions established for the roadmap. To understand what could actually be designed with Sign Again, rigorous technical testing was conducted. Bending, tensile, screw-pull, water absorption and Shore D hardness tests reveal the material's unique profile.

5.1.2 Define

In the Define/Create phase, co-creation insights were analysed to narrow the focus and formulate a clear design direction. To capture the complexity of the market's hesitation, a problem map. Through this the core problem was found and led to the establishment of the Programme of Requirements (PoR).

5.1.2.1 Problem mapping

Through the creation of a problem map (see Figure 40), the complexity of the systemic barriers was visualised to understand the causal relationships between stakeholders, economics and material constraints. This mapping process revealed that the barriers are not isolated but form self-reinforcing feedback loops that ironically lock the industry into a linear model.

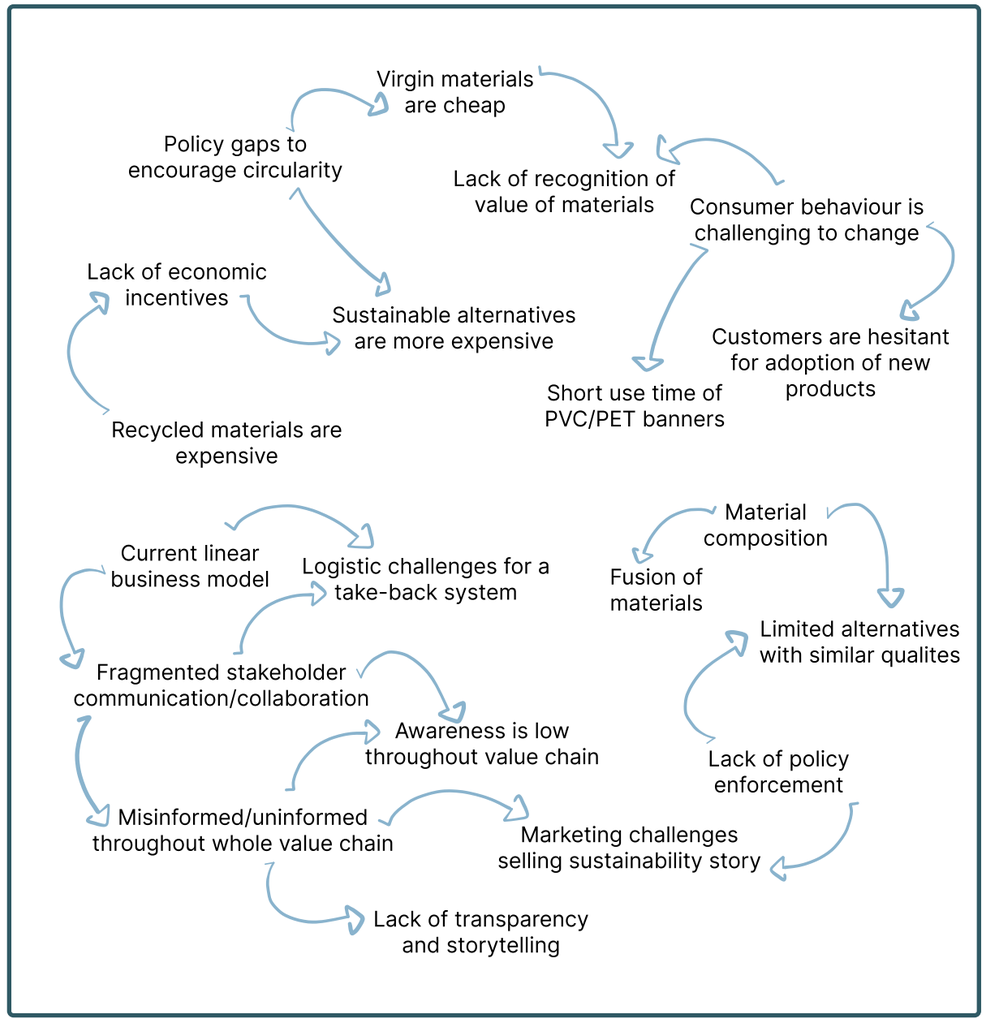


Figure 40. *Problem map print and sign industry*

As illustrated in the figure, two dominant clusters emerged from the analysis. Firstly, the economic feedback loop. The map highlights a vicious cycle driven by cost. Because 'virgin materials are cheap' and policy gaps fail to account for costly consequences, 'sustainable alternatives are more expensive'. This price disparity creates a 'lack of economic incentives' for change. Consequently, as long as 'recycled materials are expensive', the 'current linear business model' remains the most financially attractive option, preventing the scaling that would eventually lower costs.

Second, the information and communication gap. A critical insight from the map is the impact of 'fragmented stakeholder communication'. This fragmentation leads to a value chain that is 'misinformed or uninformed', resulting in 'low awareness' and a 'lack of transparency and storytelling'. Stakeholders cannot see the full lifecycle or the true value of the material, 'Marketing challenges' arise. Clients are unable to justify the higher price of circular products because the 'value of materials' is not recognised. This lack of information directly feeds into 'consumer behaviour', making customers 'hesitant for adoption' and keeping them locked in 'short use time' habits. A solution to this found gap would be to gain a better understanding of the panel material, Sign Again, by conducting several material tests. Gathering this data could fill some of the information gap and bringing this new information to the system in a thoughtful manner can also bridge the communication gap.

Based on these interconnected loops, it becomes clear that there are multiple ways to solving part of the overarching problem of the generation of PVC banner waste. It can be solved from a bottom up perspective, the technical material problem. It can also be seen from a top down perspective where there is a lack of foundation policies for companies to build of. The problem can also be addressed by adding more transparent information to the system, so that all stakeholders have to the chance to fill the knowledge gap currently present.

Synthesising the insights from the problem map and the defined scopes, the core challenge can be defined as an information and value disconnect. The technical existence of a circular material, Sign Again, is not enough to drive adoption if the market cannot perceive its value or navigate the transition. Therefore, the concrete problem statement for this project is:

> "The transition to a circular print industry is stalled because fragmented stakeholder communication and a lack of transparency prevent clients from recognising the value of sustainable alternatives. Despite the technical availability of recycled materials like Sign Again, decision makers remain locked into purchasing cheap, single-use virgin materials because they lack the actionable information and systemic incentives needed to justify the switch."

5.1.2.2 PoR strategic roadmap

The roadmap requirements ensure strategic clarity, stakeholder coordination and alignment with circular economy principles to transition the industry away from single-use virgin PVC.

R1. Production and logistics
1.1 The roadmap must define the logistics required for a functional take-back and return system for PVC banners.
1.2 The system should specify the necessary pre-treatment steps (sorting, cleaning, shredding) required for mechanical recycling.

R2. Material and end of life
2.1 The roadmap must align with the R-ladder principles, demonstrating a progression from recycling/repurposing toward rethinking and refusing virgin plastics over time.
2.2 The system must facilitate the specific infrastructure needed for the end of life management of PVC banners.
2.3 The stakeholders must establish clear material KPIs, such as percentage of return and recyclate contamination limits.

R3. Economic and systemic integration
3.1 The roadmap must integrate new circular business models, such as Product-Service Systems (PSS), to ensure materials are leased or recovered rather than sold and lost.
3.2 The system must propose actionable economic incentives to discourage the default selection of cheap virgin materials.
3.3 The strategy must align with upcoming EU 2025-2030 circular legislation, specifically EPR and recycled content mandates.
3.4 The value chain must foster cross-sector collaboration, clearly defining stakeholder roles to bridge the current communication fragmentation.

R4. Environmental sustainability
4.1 Companies must utilise transparent storytelling to educate consumers about their purchasing impact and the product's full lifecycle.
4.2 The industry must transition toward measuring and reporting CO^2 footprint reductions and waste diversion metrics.

5.1.2.3 PoR concept

The concept requirements ensure that the proposed intervention effectively bridges the knowledge gap, increases the adoption of the Sign Again material and is validated against real world industry standards.

C1. Usability and content
1.1 The concept must take a form that provides people in search of recyclate with the right information.
1.2 The concept must translate complex technical data into understandable, actionable design guidelines for technical users.
1.3 The concept must honestly showcase the mechanical realities of the Sign Again material to prevent misapplication.

C2. Lifecycle and transparency
2.1 The concept must visualise the full circular journey of the material to substantiate its sustainability claims and build trust.
2.2 The concept must provide transparent cost comparisons or value propositions that highlight the hidden disposal costs of standard linear materials versus the long-term value of recycled composites.

C3. Behaviour change and systemic integration
3.1 The concept must lower the cognitive barrier to entry, making the complex decision of sustainable procurement simple and justifiable for clients.
3.2 The concept should utilise persuasive design and storytelling techniques to actively encourage the selection of the circular material over the linear norm.
3.3 The concept must provide clear end of use instructions, explaining how the client can participate in the reverse logistics/take-back system.

5.1.3 Develop

In the Develop/Create phase, the insights gathered from the co-creation sessions and the material testing phase were synthesised to generate concrete solution directions. The Define phase revealed that the primary barrier to circularity was not only a lack of technology and policy (enforcement), but also partly a profound information and value disconnect. This is why ideation focused heavily on communication interventions.

Several preliminary concepts were explored, ranging from designing a convention, flyering, an app to videography. To validate these directions, iterative co-creation sessions were held with industry experts, printers and material manufacturers. During these sessions, low-fidelity prototypes of the strategic roadmap and the trends were presented. The feedback confirmed that stakeholders needed a "boundary object", a shared communication asset that could translate the complex mechanical properties of the Sign Again material into simple, persuasive storytelling for clients. This feedback directly shaped the development of the guidebook, a circular information tool, ensuring it was grounded in real world procurement processes and effectively addressed the market's hesitation toward recycled composites.

To gain more data on the material at hand to be informed on in the guidebook, several material tests were conducted to be able to collect specific material properties through a scientific manner. These tests enabled the material to be compared to other materials with either similar properties or other materials used in similar industries. This gives the user a good feel for what Sign Again has to offer and how it compares to material they already know.

5.1.4 Deliver

To systematically translate the initial research findings into actionable design requirements, a value mapping exercise was conducted as the final step of the methodology. This process ensures a direct alignment between the structural barriers identified during the expert interviews and the proposed circular interventions. Rather than viewing the transition as a single, overwhelming challenge, value mapping isolates specific stakeholder needs and pairs them with targeted design solutions. In the Deliver phase, the preferred concepts were refined into three distinct, implementable design results.



A strategic roadmap addresses the complex systemic and logistical barriers. It provides value by breaking down the transition into a chronological, phased timeline, offering businesses a clear, step by step path to integrate new circular business models and take-back systems over time.



The guidebook is a tangible design intervention which addresses the barrier of low environmental awareness and the lack of transparent storytelling. It provides value by translating complex technical data and sustainability metrics into an accessible procurement asset, giving companies the concrete information they need to confidently choose circular alternatives over virgin PVC.



The texture board addresses the physical uncertainties and the ‘tactile gap’ associated with new recycled composites. Because technical data alone is often insufficient for designers to specify a new material, the texture board provides value by allowing stakeholders to physically interact with the recycle by feeling its weight, rigidity and surface finish. This tangible experience demystifies the material and builds the necessary trust in its structural integrity.

By delivering both a long-term systemic vision and an immediate, practical communication tool, the final design outcomes successfully equip stakeholders to overcome adoption barriers and initiate the transition toward a circular print and sign industry.

Chapter 6.

Results co-creation

6.1 Value mapping
- 6.1.1 Trends
- 6.1.1.1 Policy and regulations trends
- 6.1.1.2 Market and consumer trends
- 6.1.1.3 Technological and material trends
- 6.1.1.4 Economic and business trends
- 6.1.1.5 Social and environmental trends
- 6.1.2 Key value drivers
- 6.1.2.1 Value mapping analysis
- 6.1.2.2 Destroyed value
- 6.1.2.3 Missed value
- 6.1.2.4 Delivered value
- 6.1.1.5 New value opportunities
- 6.3.1 Future visions

6.2 Idea mapping

6.3 Pathway mapping

6.4 Co-creation session
- 6.3.1 Co-creation results
- 6.3.1 Trends
- 6.3.1 Value drivers
- 6.3.1 Concepts
- 6.3.1 Visions
- 6.3.1 Conclusion

6.5 Designing roadmap
- 6.3.1 Phase 1: Short-term
- 6.3.1 Phase 2: Mid-term
- 6.3.1 Phase 3: Long-term

6. RESULTS CO-CREATION

6. Results co-creation

This chapter captures the start of the design phase, where the problem is further discovered through co-creation sessions. The results are concluded in a roadmap with a clear future vision which can help guide the industry to a circular economy. First ten relevant trends were found through value mapping. Next, idea mapping helped to generate concepts to fit in the mile stones. Lastly, pathway mapping ensured that the roadmap is finetuned and ready to use.

To generate the roadmap which best reflects the future vision and keeps the current strategies in mind, it is helpful to go through the process of diverging and converging activities structured in three phases layed out by Simonse, 2024. This chapter will take the project through these steps and their results.

6.1 Value mapping

The current strategic position can be understood through value mapping. The challenge here is to grasp new value opportunities from trends and technologies which shape the future vision. This will help to decide on unique value drivers. This future vision statement is grounded on these unique value drivers . The final aim of this value mapping step is to conclude on a future vision for this system to grow towards.

6.1.1 Trends

Based on the literature research and some further desktop research concerning trends and upcoming technologies within the print and sign industry, a list of relevant trends was made. The trends will help to construct stepping stones for the roadmap and make clear what can be built on top of.

6.1.1.1 Policy and regulation trends

Trend 1 - Expansion of circular economy legislation

The European Green Deal requires higher recycled content in products in general (European Commission, 2019). Besides this the EPR for plastics is expanding to non-packaging products (Netherlands Chamber Of Commerce, KVK, 2025). This means that any product made from Sign Again gains regulatory relevance as industries will seek recycled content materials.

Trend 2 - Restrictions on PVC and hazardous additives

Phthalates and chlorine-based plastics are coming under increasing scrutiny due to their environmental impact. Experts noted that PVC is already often on prohibited lists for incineration because it releases chloride. Consequently, some municipalities are restricting PVC use in events, construction and public spaces (Ortiz & European Environmental Bureau (EEB), 2024). Consequently, as disposal becomes costlier and the material itself faces tighter regulation, the demand for repurposed PVC solutions is expected to grow.

6.1.1.2 Market and consumer trends

Trend 3 - Rise of sustainable procurement

Public authorities are increasingly applying ‘green procurement’ scores to their products, while festivals, municipalities and construction companies are now requiring recycled materials to meet their own sustainability targets. This shift was confirmed by experts who noted a consistent growth in demand for circular materials in public projects and housing. This market evolution allows open ended Sign Again products to effectively target B2B markets that are increasingly driven by sustainability led procurement mandates.

Trend 4 - Short lived products shifting toward reusable systems

The events industry is actively moving to reduce single use waste (Circular Festivals, 2025), while corporate branding strategies are demanding solutions with a lower environmental impact. Interviewees highlighted that clients are looking for ‘visible circular stories’ to display in their projects. Therefore, products designed for multiple use cycles, such as temporary structures, modular panels and protective products, are becoming increasingly attractive to these sectors.

6.1.1.3 Technological and material trends

Trend 5 - Advances mechanical recycling and composite engineering

Technologies such as press moulding and compounding are becoming more accessible and efficient. Simultaneously, modular composite panels are emerging as a trending solution in both the construction and events sectors due to their versatility. Sign Again panels align well with this shift, showing high compatibility with modern tool-less assembly systems, modular kits and structural panel applications.

Trend 6 - Digital fabrication adoption

Digital fabrication technologies, including CNC routing, laser cutting and water jetting, are becoming standard manufacturing methods, shifting production capabilities toward high precision and customisation. By leveraging these technologies, Sign Again products can offer parametric, customisable or on-demand fabrication, enabling a vast open solution space.

6.1.1.4 Economic and business trends

Trend 7 - Rising disposal costs and incineration taxes

Stricter regulations are leading to landfill bans and significantly higher gate fees for mixed plastics (Belastingdienst, 2026). Experts emphasised that while landfilling or incineration is currently a 'cheap' route compared to recycling, it is becoming costlier and legally difficult. Consequently, recycling and repurposing PVC is becoming financially attractive as avoiding rising disposal costs turns waste into a valuable resource.

Trend 8 - Emerging circular business models

The market is witnessing a shift toward circular business models, including PSS, deposit-return schemes, material leasing and modular infrastructure rentals. This aligns with expert advice to focus on logistics and take-back systems as a key part of the business proposition. This suggests that Sign Again products could benefit from being integrated into service-based circular ecosystems rather than being sold purely as one-off goods.

6.1.1.5 Social and environmental trends

Trend 9 - Social enterprises integrated in circular systems

The processes of sorting, cleaning and remanufacturing are increasingly linked with social employment initiatives. Expert interviews confirmed that the social value created through these processes is often a key selling point that offsets higher recycling costs. Sign Again workflows can thus be designed to support community based job creation, adding a strong social narrative that serves as a key differentiator.

Trend 10 - Demand for low-carbon, durable materials

Both consumers and businesses are actively seeking low-carbon alternatives to traditional materials like steel, virgin plastics and wood. This creates an opportunity for Sign Again to appeal to markets that require weather-resistant, impact-resistant and long-lived materials without the carbon footprint of virgin resources.

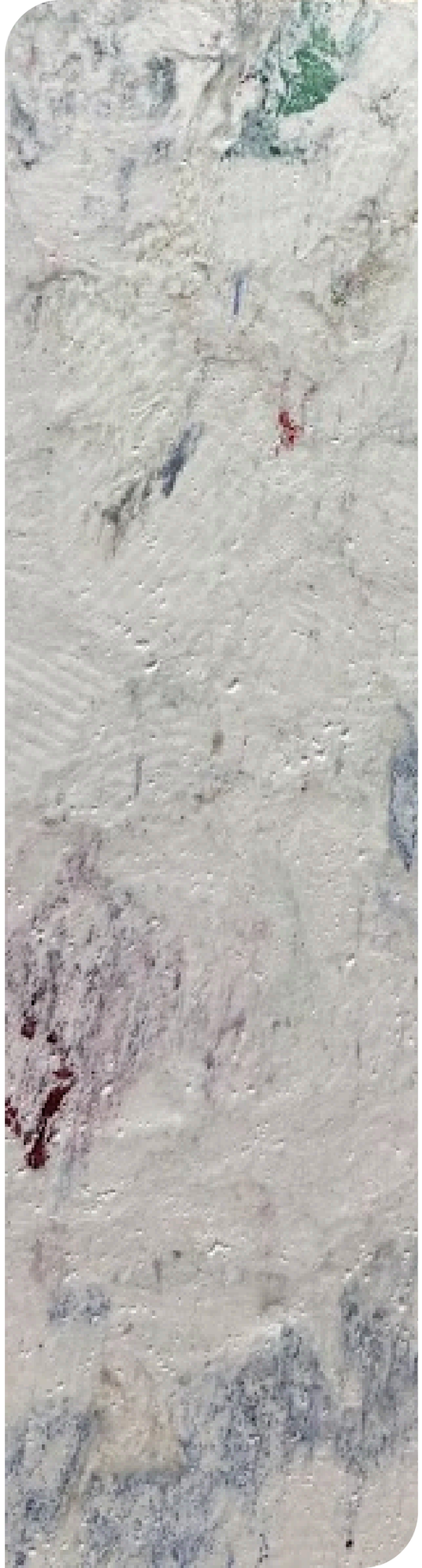


Figure 41. *Sign Again*

6.1.2 Key value drivers

A key value driver per trend category makes sure that when designing for a solution all areas of the unmet needs are covered as much as possible.

1. Compliance capability of businesses with evolving EU legislation
2. Creating awareness for business and consumers relating to their usage habits
3. Being able to transform banner waste into valuable material
4. Create a new circular business model which enables recycling companies to grow
5. Creating cross-sector collaboration culture to enable closed loops

6.1.3 Value mapping analysis

To understand the full potential of the Sign Again material, a value mapping analysis was conducted. This analysis contrasts the value currently lost in the linear system against the potential value that can be captured through circular intervention. The findings are categorised into four distinct areas: destroyed value, missed value, delivered value and future value opportunities.

6.1.3.1 Destroyed value

In the current situation, a linear model, significant economic and material value is systematically destroyed. The primary end of life scenario for banners is incineration, resulting in a 100% loss of material value. No successful reuse loops or standardised take-back systems currently exist, this means manufacturers and printers lose out on potential secondary revenue streams. Furthermore, the linear disposal of these materials contributes no branding equity and generates negligible social value, effectively reducing a durable resource to a cost liability.

6.1.3.2 Missed value

There is significant untapped potential in the waste stream that Sign Again is uniquely positioned to capture, spanning material, functional and market dimensions. Regarding material value, the intrinsic properties of PVC banners, specifically their weather resistance and strength, make them ideal candidates for repurposing into durable, long-life products. By transforming single-use event materials into permanent applications, the system captures long-term use value that is currently ignored. Functionally, the structural rigidity and strength of the processed material make it a viable technical replacement for conventional materials such as wood, HDPE or composite boards, particularly in applications requiring protection, separation or outdoor durability. This aligns with a growing, unfulfilled market demand for products containing recyclate, driven largely by municipal 'green procurement' policies and an events industry increasingly seeking modular, reusable infrastructure.

6.1.3.3 Delivered value

Implementing Sign Again material delivers tangible value across environmental, social and economic dimensions. Environmentally, the material actively prevents banner incineration, thereby lowering the carbon footprint compared to virgin alternatives and stabilising PVC waste into durable, long-lasting applications. From a social perspective, the production process supports local recycling loops and creates opportunities for social workplaces, specifically in the labour intensive sorting and cleaning phases. Economically, the model converts a waste stream into a sellable commodity, creating new circular business opportunities for both printers, who can offer take-back services and recyclers.

6.1.3.4 New value opportunities

The analysis reveals an expansive open-ended design space for Sign Again, where the material's properties align with several emerging market trends. The most immediate opportunity lies in modular systems, such as event flooring, temporary dividers, interlocking tiles and reusable construction site elements. Simultaneously, the material is well-suited for infrastructure and other outdoor applications where durability is necessary. Beyond physical products, there is significant potential for Circular PSS. This involves shifting from product sales to service models, such as the rental of modular panels or standardised components suitable for multiple distinct applications. These systems can be further enriched through social circularity, where components are assembled in social workplaces or community made outdoor installations. Finally, the material offers opportunities for aesthetic repurposing in high-visibility applications like interior architecture and creative festival structures, which serve to visually communicate the circular story.

The value mapping indicates that the strongest opportunity space for Sign Again lies in modular, durable, large-scale products that can replace virgin plastics, wood or composites. Specifically, the material is best suited for products that cycle repeatedly within B2B or municipal loops, underpinned by system-based circular services.

6.1.4 Future visions

The process of value mapping resulted in future visions for the system to give it direction and a goal to grow towards, these can be found below.

Overarching vision

> *"A future where PVC banners are fully recovered, mechanically recycled and transformed into durable, high-value products through a circular system supported by industry, government and users."*

1-Year Vision (Short Term)

> *"A functional and reliable circular pipeline is established: PVC banners are collected consistently, processed through the Sign Again method and transformed into early pilot products that prove technical feasibility and stakeholder commitment."*

3-Year Vision (Mid Term)

> *"Sign Again material becomes a standard recycled feedstock, supported by formal take-back schemes, partnerships with printers and municipalities and a growing product family of durable, modular circular solutions."*

15-Year Vision (Long Term)

> *"PVC banner waste is fully integrated into a Europe wide regenerative system, where it circulates its maximum through high-value applications. All the while there is an active search for more sustainable innovative material alternatives, so that PVC can eventually be refused all together."*

6.2 Idea mapping

In the roadmapping process, idea mapping serves as the vital link between uncovered value opportunities and concrete technological applications. According to Simonse (2024), this stage involves divergent technology scouting and user value research, which then converge into the generation of specific product-service ideas. For this project, the 'technology' centers on the mechanical recycling capabilities of the Sign Again process, while the 'user values' are driven by the need for sustainable procurement, transparent communication and overcoming the current market's reliance on cheap virgin plastics.

During the idea mapping phase, the goal was to identify 'blank spots' in the current linear print and sign industry and fill them with circular value propositions. Using the previously identified trends as a foundation, concepts were brainstormed and plotted along the time-paced roadmap. The mapping generated distinct interventions based on the timeline.

Short-Term: The primary 'blank spot' identified was stakeholder awareness and material transparency. This led to the conceptualisation of the playbook, designed to bridge the knowledge gap between printers and end-clients.

Mid-to-Long Term: Ideas focused on finding appropriate applications for the heavy yet flexible nature of the Sign Again material. Concepts such as modular event flooring, road plates and durable signage were mapped out.

By matching the recycled material's unique physical properties with these specific market needs, the idea mapping phase successfully populated the roadmap with actionable concepts.

6.3 Pathway mapping

The final stage of the roadmapping process is pathway mapping. This phase transitions the generated ideas into a structured, chronological design program roadmap by allocating, ordering and linking innovation activities along the future timeline. Pathway mapping requires overcoming the tensions between 'market pull' and 'technology push' by synchronising efforts and acknowledging practical constraints, such as resource limits, lead times, and logistical barriers. For the transition of the print and sign industry, the pathways were mapped to reflect a gradual shift up the R-ladder (from recycling, to rethinking and ultimately refusing). The pathways were structured as follows:

Short-term pathway (raising awareness):
The immediate pathway links the deployment of the concept to the establishment of functional pilot collection systems. The focus here is on overcoming communication constraints to trigger initial market pull for recycled alternatives.

Mid-term pathway (changing the norm):
This pathway scales up the concepts generated during idea mapping, introducing PSS for applications like modular flooring. It explicitly links the technological advancement of mechanical recycling with the implementation of formal take-back schemes, addressing the logistical and financial constraints of the industry.

Long-term pathway (raise the adoptability):
The final pathway projects the alignment of these circular business models with upcoming EPR legislation. The linked activities illustrate how the industry can eventually phase out the use of virgin PVC for temporary signage altogether.

By linking these activities and constraints, the pathway mapping provides a clear, strategic sequence. It ensures that the proposed concepts are not viewed as isolated ideas, but rather as interconnected steps guiding stakeholders from the current linear reality toward a collaborative, circular future.

6.4 Co-creation session

Through conducting co-creation sessions it was possible to get a more concrete idea for the design and retrieve insights on the accuracy of how the systems had been captured thus far. A preliminary roadmap containing future visions per time pillar, concept ideas and the holistic goal for the system change was shown to the participants. In the first session the roadmap was discussed with four colleagues of Horizonteer and the second co-creation session was conducted with two clients who work with Sign Again.

During the co-creation the participant were asked to validate, adjust and supplement the trends, value drivers, concepts and visions. This way all these elements went through an iteration and would be more relevant for the roadmap.

6.4.1 Co-creation results

To gain concrete insights into the trends, concepts and visions it was valuable to set up co-creation sessions with relevant and knowledgeable stakeholders. The co-creation was split up into two groups, one with colleagues of the innovation design agency Horizonteer and one session was with two experts who work with Sign Again. Both these groups of people have real life experience with developing

The preparation for the co-creation session involved thinking of what information to show to be able to receive the wished feedback. A more holistic view is gained to what the roadmap should and should not entail to get to the end goal. The set up for these sessions can be found in Appendix D.1.

6.4.1.1 Trends

During the co-creation sessions, the ten relevant trends were discussed for their relevance, importance and urgency to make changes in the system. Based on these discussions the trends were ranked on these factors, which resulted on the list below, with the most important trends listed first.

- Trend 2: Restrictions on PVC and hazardous additives
- Trend 3: Rise of sustainable Procurement
- Trend 1: Expansion of circular economy legislation
- Trend 10: Demand for low-carbon, durable materials
- Trend 7: Rising disposal costs and incineration taxes
- Trend 4: Short-lived products shifting toward reusable systems
- Trend 9: Social enterprises integrated in circular systems
- Trend 8: Emerging circular business models
- Trend 6: Digital fabrication adoption
- Trend 5: Advances in mechanical recycling and composite panel engineering

This list represents which trends are more important and currently relevant for a transition towards a more circular economy. Putting more attention towards the top most trends will help the transition the best and the fastest.

6.4.1.2 Value drivers

During the co-creation sessions, the initial value drivers were evaluated for their relevance specifically to the PVC banner waste stream. Based on stakeholder feedback, the drivers were slightly refined for clarity and, most importantly, rearranged in order of immediate importance to the industry.

Original list:

1. Compliance capability of businesses with evolving EU legislation
2. Creating awareness for business and consumers relating to their usage habits
3. Being able to transform banner waste into valuable material
4. Create a new circular business model which enables recycling companies to grow
5. Creating cross-sector collaboration culture to enable closed loops

Adjusted list in order of importance:

1. Creating awareness among businesses and consumers regarding their usage and purchasing habits
2. Creating circular business models that encourage sustainable alternatives and enable recycling companies to grow
3. Transforming PVC banner waste into a high-quality, valuable material.
4. Cultivating a culture of cross-sector collaboration to enable closed material loops
5. Ensuring the compliance capability of businesses with evolving EU circular economy legislation

The rearrangement of these drivers reflects a key insight from the co-creation sessions: while technological solutions and upcoming legislation are important, the most immediate bottleneck in the current system is human behaviour. Stakeholders emphasised that without first creating awareness and market demand (driver 1), there is no foundation to build profitable circular business models (driver 2). The physical material transformation (driver 3) and systemic collaboration (driver 4) act as the practical execution of these models. Finally, while EU legislation (driver 5) is a critical push factor, experts noted that policy enforcement is currently too weak to be the primary driver of daily business decisions, making market driven awareness the top priority.

6.4.1.3 Concepts

By showing low fidelity sketches with a wide range in desirability, viability and feasibility the participants were able to share any thoughts, feedback and additions freely. Here they had notes on exactly that, resulting in a rough estimation of where the concepts would land in a Venn diagram for desirability, viability and feasibility shown in Figure 42.

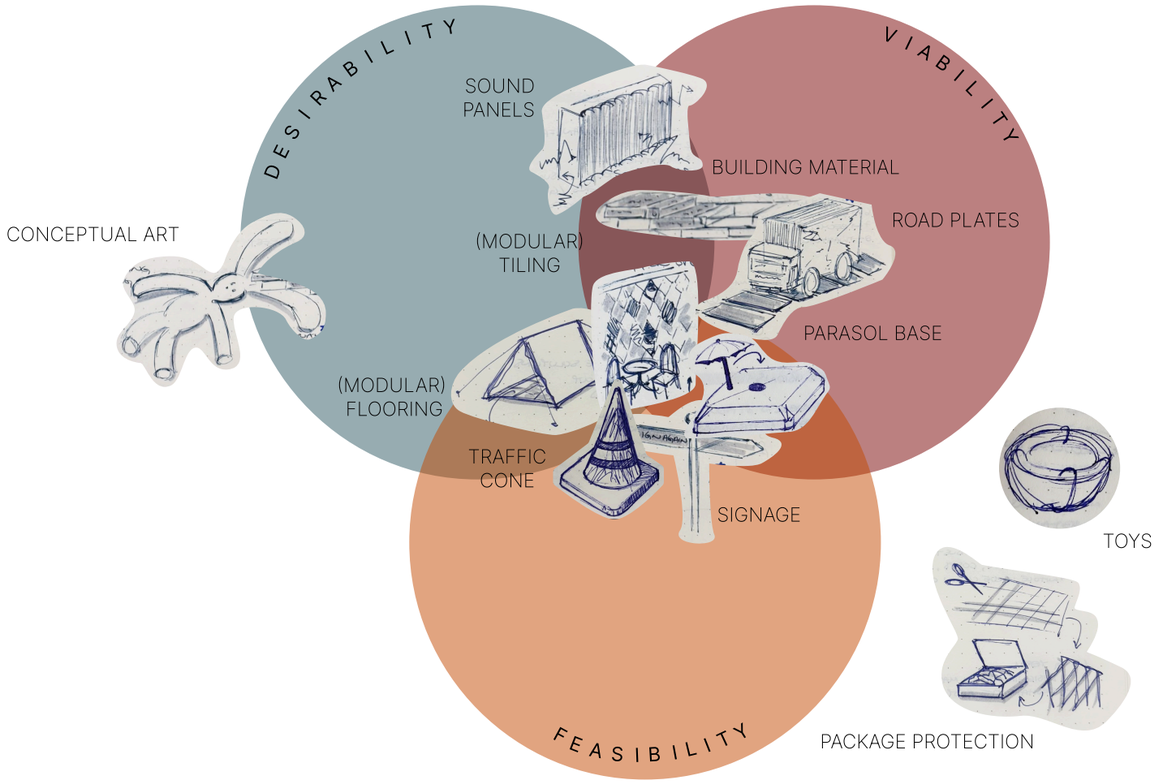


Figure 42. *Concept Venn diagram overview across desirability, viability and feasibility*

Most of the concepts are found in or near the centre of the diagram, meaning they score well on either two or three of the aspects. Here flooring, signage, tiling, parasol base, traffic cone and road plates have the most potential to be successful on the market. Some of the concepts fall (partly) outside of the diagram, as they are too farfetched or clearly unsuitable for the material, such as risk for harmful leakage.

6.4.1.4 Visions

Lastly, the future visions were modified based on the feedback from the co-creation sessions to communicate a clearer, more actionable goal. A key insight from the experts was that a '100% circular banner system' may be an unrealistic long-term goal because PVC/PET composite is inherently a 'monstrous hybrid'. Therefore, while repurposing is the best short-term solution, the ultimate long-term vision must include the phasing out (refusing) of virgin PVC for temporary signage. The refined visions are as follows:

Overarching vision: A future that maximises the material recovery of PVC banner waste through high-value repurposing, functioning as a transitional bridge toward an industry norm that ultimately refuses virgin PVC and embraces fully sustainable alternatives.

Short-term (5 years) A functional pilot system is established that consistently collects and transports post-consumer PVC banners. Initial material processing is validated to demonstrate technical and mechanical viability for material reuse, leaving room to explore alternative applications and securing the commitment of key stakeholders.

Mid-term (10 years): Mechanically recycled material achieves a competitive value proposition against virgin plastic, backed by standardised quality and formal take-back schemes. Circular business models are integrated, leading to a growing, reliable circular feedstock while awareness campaigns actively begin phasing out virgin banners for temporary signage.

Long-term (20 years): PVC banner material is fully integrated into a regenerative Europe wide system. Its circulation indefinitely displaces the use of virgin plastics and consistently meets all upcoming EU recycled-content and EPR legislation, moving toward a system that ultimately refuses monstrous hybrid materials in favor of true circular alternatives.

6.4.2 Conclusion

Throughout the two co-creation sessions, it became clear that the core problem extends beyond the technical challenges of material recycling; it is deeply rooted in the downstream adoption phase. The primary obstacle to achieving a circular economy in this sector is a systemic lack of awareness among both companies and end-consumers. Furthermore, businesses are apprehensive about adopting Sign Again as a product to sell to their clients. The issue here is not the mechanical qualities of the board material itself, but rather the lack of clear, transparent communication regarding its environmental impact, its functional equivalence to virgin materials, and how it fits into a viable business model.

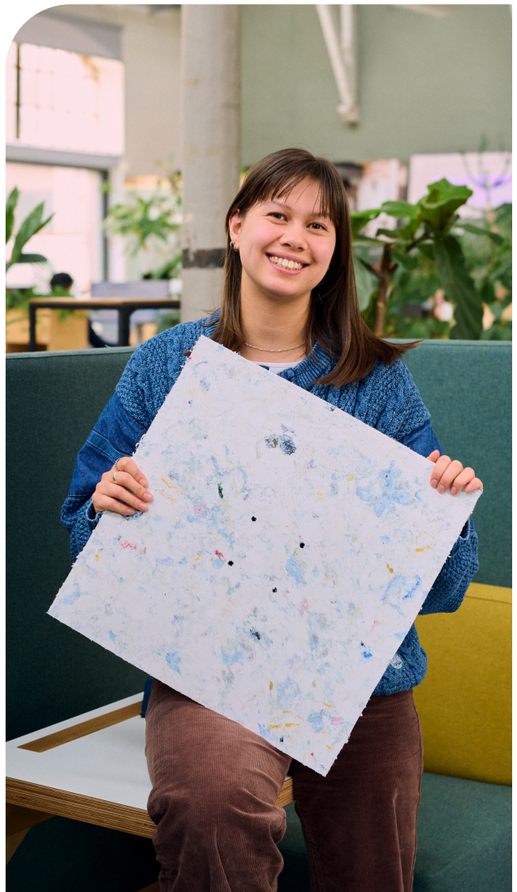


Figure 43. *Author holding a panel of Sign Again (Horizonteer, 2026)*

6.5 Designing roadmap

To synthesise the findings from the value mapping, trend analysis, and expert co-creation sessions, a strategic design roadmap was developed (see Figure 45). The roadmap serves as a chronological guide to navigate the transition from the current linear operational model to the desired circular future for PVC banners.

Rather than viewing the transition as a single leap, the roadmap structures the pathway across three distinct time pillars: short-yerm (5 years), mid-term (10 years) and long-term (20 years). Furthermore, because the expert interviews revealed that the barriers are multi-dimensional (spanning economic, systemic and environmental domains), the roadmap organises the necessary interventions into three parallel tracks: awareness, technology and systemic.

As the timeline progresses, the industry's position on the R-ladder also advances, moving from lower-tier material recovery (Recycling) toward higher-tier systemic prevention (Refusing virgin materials).

6.5.1 Phase 1: short-term (5 years)

The goal for this phase is 'System validation and logistical proof', where the R-Ladder focus is on recycle and repurpose. The immediate focus of the roadmap is to establish a functional pilot system and overcome the initial barrier of stakeholder ignorance.

- Awareness:

The primary intervention in this phase is the deployment of an information tool. This tool bridges the knowledge gap by translating complex technical data (such as the specific material properties and how to handle the material) into actionable, transparent storytelling. This helps justify the initial cost disparity compared to virgin PVC.

- Technology:

Product development focuses on low-risk, high-feasibility applications (e.g., basic signage or conceptual festival art). These designs must embrace the monstrous hybrid reality of the heavy, fused PVC/PET recyclate rather than forcing it into lightweight structural applications.

- Systemics:

To prove logistical viability, micro-take-back schemes must be established with a select group of dedicated printing partners and event organisers, fostering early cross-sector collaboration.



Figure 44. *Co-creation session (Horizonteer, 2026)*

6.5.2 Phase 2: mid-term (10 years)

For the second phase the focus is on scaling, standardisation and getting a competitive advantage. The R-Ladder focus is put on the reuse, refurbish and remanufacture steps.

Once the pilot proves successful, the roadmap shifts toward scaling the operations and changing industry norms.

- Technology:

The product portfolio expands into the high-value concepts identified during the idea mapping phase, such as modular event flooring, interlocking tiling and road plates.

- Systemic:

To support these modular products, the industry must transition from traditional linear sales to PSS. By leasing out durable panels, reverse logistics are built directly into the business model. Simultaneously, formal take-back contracts should be established with municipalities to align with their rising green procurement targets.

- Awareness:

The information tool evolves from an educational intervention into a standardised procurement asset, helping clients actively track their carbon savings and compliance with circular targets.

6.5.3 Phase 3: long-term (20 years)

In the last time pillar the goal is for a complete systemic transition to take place and have companies be able to be compliant with new policies. The R-Ladder focus is to rethink and refuse unsustainable materials.

The final phase of the roadmap acknowledges that mechanically recycling a composite material is a transitional solution. The ultimate goal is a fully regenerative system.

- Systemic:

The Sign Again ecosystem becomes fully integrated with EU EPR schemes and the CEAP. Heavy taxation on virgin PVC makes the circular system the most economically viable default across Europe.

- Technology:

While existing Sign Again panels are kept in closed loops (i.e. re-shredding old panels into new ones), heavy R&D investment pivots toward designing 100% mono-material banners or reversible chemical coatings to solve the fusion bottleneck entirely.

- Awareness:

The ultimate success of the awareness campaigns and the information tool culminates in the market actively refusing short-lived, single-use virgin PVC banners. The industry norm shifts entirely to reusable digital signage, mono-materials or circular PSS models.

To synthesise the findings from the value mapping, trend analysis and co-creation sessions, a strategic roadmap was developed (see following page). The roadmap serves as a visual guide to navigate the transition from the current linear model to the desired circular future. Through pathway mapping, the generated concept ideas (such as modular flooring and durable signage) were aligned with the specific user values and technological milestones defined in the short, mid and long-term visions.

STRATEGIC ROADMAP FOR A CIRCULAR TRANSITION WITH SIGN AGAIN

NOW 2025

PVC banners are primarily a disposable, single-use product following a linear business model. Mechanically recycled material (e.g., Sign Again) exists only as a niche, high-cost initiative struggling against cheap virgin materials and lacking incentives.

2030

SHORT-TERM [5 YEAR]

A functional pilot system is established that consistently collects and transports post-consumer PVC banners. Initial material processing is validated to demonstrate technical and mechanical viability for material reuse, leaving room to explore alternative applications and securing the commitment of key stakeholders.

Goal: System validation and logistical proof

2035

MID-TERM [10 YEARS]

Standardised recycled materials rival virgin plastics through formal take-back schemes. Integrated circular models ensure a reliable feedstock, while campaigns actively phase out temporary virgin banners.

Goal: Scaling, standardisation and competitive advantage

2045

LONG-TERM [20 YEARS]

A regenerative European system indefinitely displaces virgin plastics and meets EU legislation, ultimately phasing out monstrous hybrids in favour of true circular alternatives.

Goal: Complete systemic transition and policy compliance

RECOVER
RECYCLE
REPURPOSE
REMANUFACTURE
REFURBISH
REPAIR
REUSE
REDUCE
RETHINK
REFUSE

1. SYSTEMIC
Launch local banner take-back schemes. Use rising incineration taxes to incentivise material returns.

2. TECHNOLOGY
Use CNC fabrication and mechanical recycling to create flat-pack pilot products, proving Sign Again's potential for high-quality, rigid applications.

3. AWARENESS
Deploy the guidebook to capture market demand. Use transparent storytelling to communicate the lifecycle benefits of repurposing over virgin materials.

4. AWARENESS
Embed the playbook into B2B contracts as a mandatory asset. Mandate circular material selection to standardise sustainable procurement and track waste diversion.

5. TECHNOLOGY
Shift product design toward reusable, modular event flooring instead of single-use signs to guarantee multiple lifecycles before re-shredding.

6. SYSTEMIC
Scale take-back infrastructure through formal leasing contracts. Partner with social enterprises to manage the labor-intensive sorting, cleaning, and shredding of feedstock.

7. SYSTEMIC
Leverage EPR laws and EU restrictions to phase out linear systems. Achieve zero virgin plastic use through a standardised, circular infrastructure.

END GOAL

The print and sign industry is CO^2 neutral through their redesign, reuse and recycling.

FUTURE VISION

The full value chain in the print and sign industry has a collaborative relationship. A circular economy is the base of the system and supports all the decisions made for products.

RAISE AWARENESS

SYSTEMIC
Rising disposal costs & incineration taxes

TECHNOLOGY
Advances in mechanical recycling
Digital fabrication adoption

AWARENESS
Demand for low-carbon, durable materials

CHANGE THE NORM

AWARENESS
Rise of sustainable procurement

TECHNOLOGY
Short-lived products shifting toward reusable systems

SYSTEMIC
Emerging circular business models
Social enterprises integrated in circular systems

RAISE THE ADOPTABILITY

SYSTEMIC
Restrictions on PVC & hazardous additives
Expansion of circular economy legislation

Figure 45. *In between stage of strategic roadmap*

Chapter 7.

Material testing

7.1 Banner pull test
- 7.1.1 Banner pull test setup
- 7.1.2 Banner pull test results

7.2 Bending test
- 7.2.1 Bending test setup
- 7.2.2 Bending test results

7.3 Tensile strength test
- 7.3.1 Tensile strength test setup
- 7.3.2 Tensile strength test results

7.4 Water absorption test
- 7.4.1 Water absorption test setup
- 7.4.2 Water absorption test results

7.5 Screw pull test
- 7.5.1 Screw pull test setup
- 7.5.2 Screw pull test results

7.6 Shore test
- 7.6.1 Shore test setup
- 7.6.2 Shore test results

7.7 Conclusion

7. Material testing

This chapter covers the setup, implementation and results of the technical materials tests of the Sign Again material. Various tests were conducted to gain a better understanding of the material and in what context it can be used best. It is also discussed how it compares to existing materials in those sectors and what materials have similar qualities. Data will be gathered for a bending test, tensile strength test, water absorption test, screw pull test and hardness test.

It is important to define Sign Again not as a homogeneous plastic, but as a stochastic (unpredictable) composite. The material consists of shredded PVC coated PET mesh of varying sizes and orientations, the mechanical properties are probabilistic rather than absolute. Consequently, the variance observed in the following tests is an inherent material characteristic; 'outliers' in the data represent the physical reality of the material's heterogeneous composition, where local concentrations of PET fibers or PVC layers dictate performance.

7.1 Banner pull test

As a base line to see how strong the 'raw' material is, a pull test was conducted with various layers of shredded banner. This gives insights into how the materials acts before it goes through any further recycling and other manufacturing processes.

7.1.1 Banner pull test setup

The instrument was set up with a 500 kg sensor and clamps at the bottom and the top. The exact setup can be seen in Figure 46. Pieces of shredded PVC banner, 20 by 50 mm, were gathered and bundled together for a total of three test per layer amount, going from 1 layer up to 7 layers. For further details of the software set up refer to Appendix E.1.

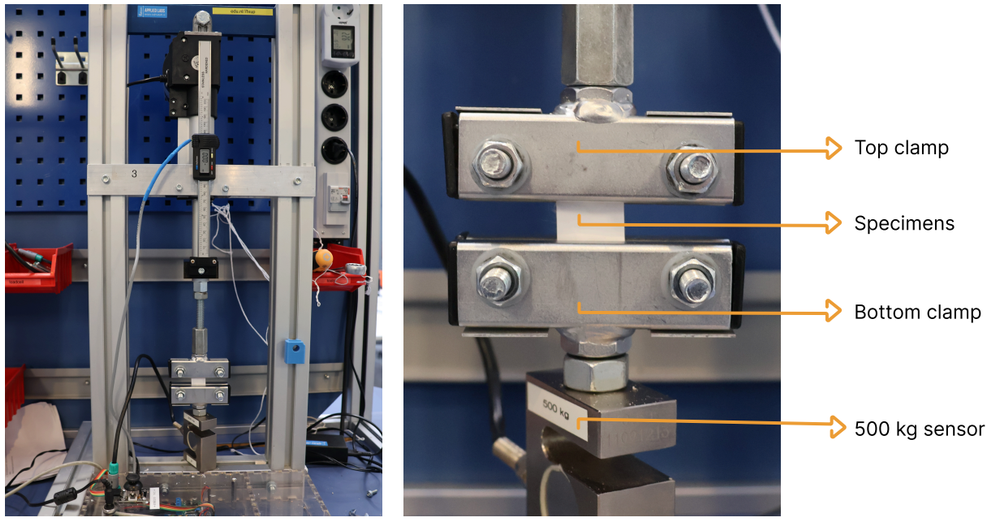


Figure 46. *Setup banner pull test*

This range was selected because visual microscopic inspection reveals that the Sign Again material is typically composed of approximately 4 to 7 compressed layers (see Figure 47). However, this composition can vary drastically per panel and even within specific sections. This is due to the shredded banner fragments not aligning uniformly, they frequently overlap or curl onto themselves during the thermal pressing process

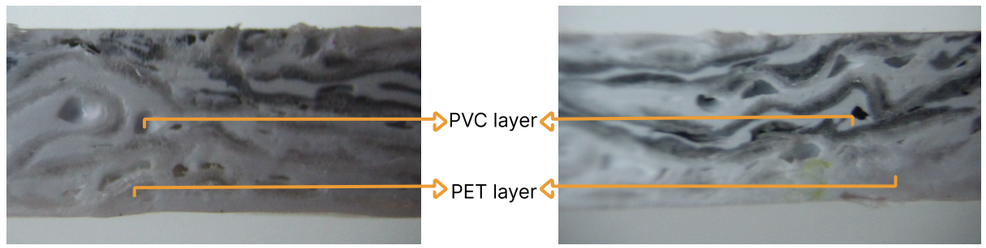


Figure 47. *Microscopic side view of Sign Again layers*

7.1.2 Banner pull test results

In this chapter the results of the banner pull tests are discussed, this test was conducted to get a feel for how the 'raw' material compares to its further manufactured variant Sign Again. Below in Tables 5-7 the results of the test can be found. Data of all three tests per layer amount are shown with their averages below it. With these results it becomes apparent that with an increase of layers more force can be applied until one or more of the layers snap. However, the elongation stays roughly similar; between 10-20 mm. Some results skew from the expectation such as all the test with 2 layers, where all the measured elongations were rather low without a clear cause and test 7.3, where this could be due to slippage of banner layers during the test. For this reason test 7.3 will be left out of the measured averages. Another notable result is where the measured force is remarkably higher than the average and the extension remarkably lower than its average, this can be seen in test 3.3, 4.3 and 5.3. A possible explanation for this could again be issues with not clamping all the layers securely enough.

Table 5. *Banner pull tests 1.1-3.3 results*

Value measured	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3
Max. elongation (mm)	22.04	22.82	17.22	5.49	5.72	7.42	11.06	17.97	8.54
Avg. max. elongation	20.69			6.21			12.52		
Max. force (N)	308.65	921.03	354.13	629.70	1088.06	907.99	1245.00	799.53	1508.46
Avg. max. force	527.94			875.25			1184.33		

Table 6. *Banner pull tests 4.1-5.3 results*

Value measured	4.1	4.2	4.3	5.1	5.2	5.3
Max. elongation (mm)	11.53	17.47	7.74	26.01	13.87	5.86
Avg. max. elongation	12.25			15.25		
Max. force (N)	1326.61	1022.83	1425.55	1301.17	567.68	1677.56
Avg. max. force	1258.33			1182.14		

Table 7. *Banner pull tests 6.1-7.3 results*

Value measured	6.1	6.2	6.3	7.1	7.2	7.3
Max. elongation (mm)	25.63	20.86	31.67	15.93	12.21	43.42
Avg. max. elongation	20.05			14.07		
Max. force (N)	1090.60	3003.13	1771.88	1893.32	1811.52	310.64
Avg. max. force	1955.20			1852.42		

The banner layers would often rip at the top of the sample, where it was clamped (see Figure 48, c). This is probably due to the samples being a rectangular shape rather than a dog bone, meaning their the weak spot is at the clamp. Nevertheless the test gave a good indication of how strong the material is and how much it can be stretched until it plastically deforms.



(a) (b) (c)

Figure 48. *Banner pull tests samples 1.2 (a,b) and 6.3 (c)*

The force/extension graphs are shown in the same scale so that it is immediately visible how each layer was effected during the pull test, for a graph of every test see Appendix E.2. On the y-axis the Force (N) is displayed till 2000 N and on the x-axis the Extension (mm) is measured till 30 mm with test 7.1 (Figure 49 (d)) being an outlier going to 50 mm.

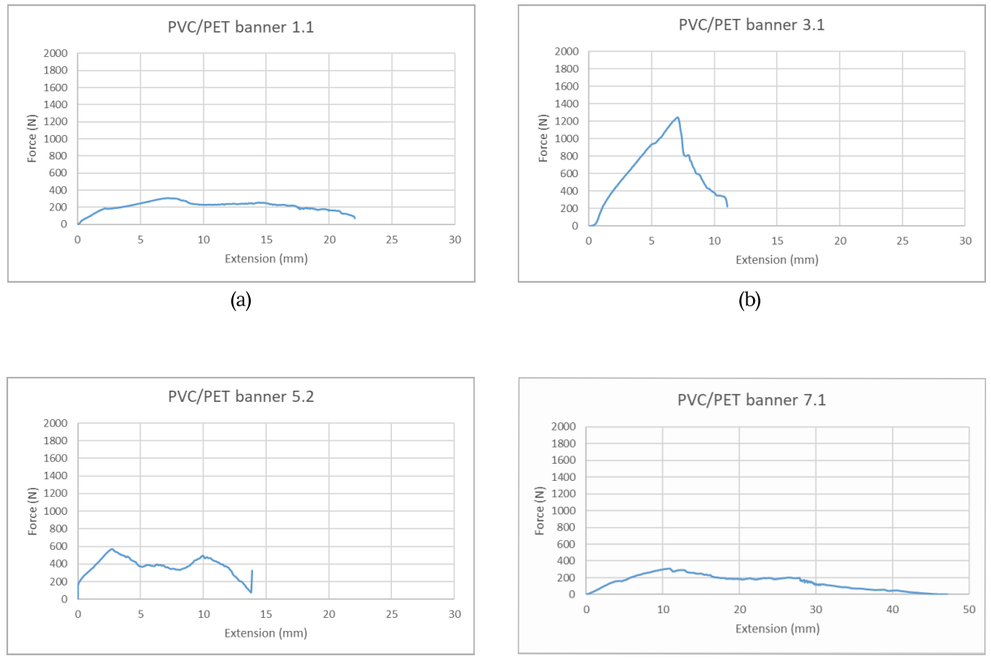


Figure 49. *Banner pull tests results visualised in graphs*

The graphs e and f in Figure 49 show the averages of all the tests per sample layer. The graph in Figure 49 (e) has a clear steady increase in force needed when the amount of layers increase along side it. How the extension per layer amount changes, seen in the graph in Figure 49 (f), is not as clear. It rather fluctuates inconsistently throughout the tests. First of all, if one of the layers tears but the test continues because the other layers remain intact, the test duration is extended much longer than tests where the instrument stopped immediately after the first break. Another reason could be the uneven distribution of tension across the manually clamped layers, causing some layers to slip or bear more initial load than others before breaking.

7.2 Bending test

A three point bending test, according to Instron & Thackeray (2026), measures the flexural properties of a material while under a bending strain or deflection. The universal testing system ASTM D790 was used to prepare the specimens, set up and conduct the tests.

7.2.1 Bending test setup

For the bending test the standardisation ASTM D790 was used and its procedure was followed (Instron & Thackeray, 2026). Six samples were prepared with the measurements 80 mm by 12.7 mm, see Figure 50.

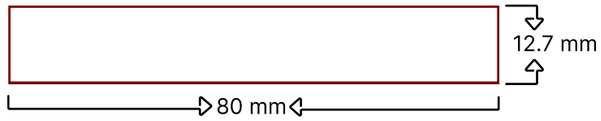


Figure 50. *Bending test sample size*

The samples were all individually measured to gather their width, length, thickness and their surface area. Table 8 shows this data per sample and their averages.

Table 8. *Bending test sample measurements*

Value measured	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Width 1	12.70	13.00	12.65	12.45	12.70	12.90
Width 2	12.20	12.95	12.85	12.65	12.90	12.70
Width 3	12.15	12.80	12.95	13.00	13.10	13.00
Width Avg. (w)	12.35	12.92	12.82	12.70	12.90	12.87
Thickness 1	3.50	3.50	3.15	3.30	3.20	3.15
Thickness 2	3.55	3.40	3.25	3.20	3.20	3.20
Thickness 3	3.55	3.35	3.30	3.15	3.15	3.20
Thickness Avg. (t)	3.53	3.42	3.23	3.22	3.18	3.18
Span (L=16*(t))	56.53	54.67	51.73	51.47	50.93	59.93
Area (A=w*t)	43.64	44.13	41.44	40.85	41.07	40.96
Rate mm/min	18.82	17.02	14.42	14.20	13.76	13.76

The instrument was setup to clamp the supports at the bottom and at the top the loading nose, like in Figure 51. There needed to be an overhang of minimum 10% of the total length on either side of the supports, the general rule Length = 16 * Thickness + 20%, this resulted in the total length being 80mm. The support span (L), the distance between the two bottom supports are calculated with the following formula: Span (L) = 16 * Thickness (t). This results to the supports being set to 51 mm apart, with the samples having an overall average thickness of 3.22 mm. The rate of the loading nose was set to 2 mm/min, $R=\frac{ZL^2}{6d}$. For further detail see Appendix E.3.

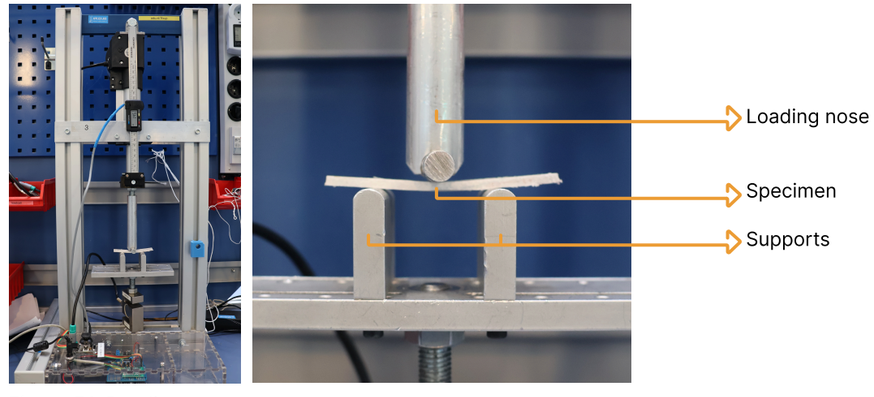


Figure 51. *Bending test setup*

7.2.2 Bending test results

Although the bending tests followed the ASTM D790 protocol, the specimens did not exhibit traditional brittle failure or a distinct 'snap' due to the inherent flexibility and high ductility of the composite. Instead, the samples conformed entirely to the radius of the loading nose (see Figure 52 (c)) and reached the maximum deflection limit of the machinery, contacting the base of the support fixture without fracturing (see Figure 52 (d)). Because the material did not experience a sudden drop in load, the testing software could not automatically detect a failure point, meaning structural damage such as tearing could only be identified through visual inspection after the test concluded. This behaviour indicates that the primary 'failure mode' for Sign Again is functional deformation rather than catastrophic breakage. Therefore, for load-bearing applications like event flooring, the design limit must be defined by the flexural modulus (stiffness) rather than the ultimate flexural strength. Consequently, while these results confirm the material's high flexibility, the quantitative data should be interpreted as a practical estimation of performance rather than a precise determination of a rupture point. A recommendation for finding a more accurate flexural strength and modulus for Sing Again might be to use a a 4-point bend test in accordance with ASTM D6272.

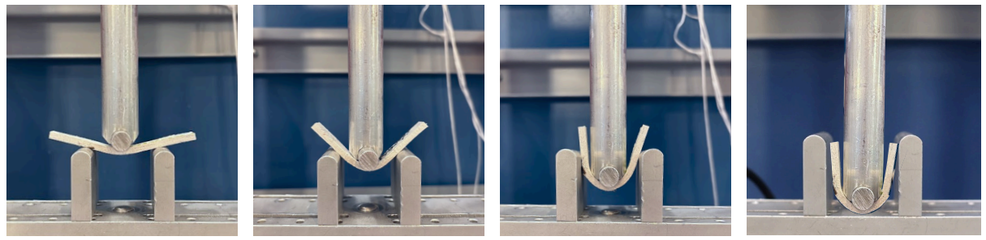


Figure 52. *Bending test sequence*

The results for the samples calculate the flexural strength (S) and the flexural modulus (E), both in MPa. For the formulas, $S=\frac{3PL}{2bd^2}$ and $E=\frac{L^3m}{4bd^3}$, the loads on the samples were needed and the slope of the initial portion of the force-extension curve. The graphs of the force-extension curves can be found in Appendix E.4. Table 9 shows all the results per sample.

Table 9. *Bending test result values*

Value measured	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Thickness Avg. (t)	3.53	3.42	3.23	3.22	3.18	3.18
Span (L=16*(t))	56.53	54.67	51.73	51.47	50.93	59.93
Width Avg. (w)	12.35	12.92	12.82	12.70	12.90	12.87
Maximum load (N)	37.58	54.41	44.95	44.51	48.63	41.87
Slope	1.99	10.22	5.13	3.48	4.21	4.66
Flexural strength	20.67	29.59	26.03	26.15	28.42	24.53
Flexural modulus	164.66	810.26	409.58	280.45	334.25	370.93

The conclusion of the values are that Sign Again has a low flexural modulus with a range of ~165-805 MPa. The flexural strength is also low with a range between ~20-30 MPa. This means the material is highly flexible and only little force is needed to bend or even kink the material. To compare, flexible PVC (Shore A65) has a modulus of 6-7 MPa and strength of 14-15 MPa (Ansys, Inc., 2025). PET (unfilled, semi-crystalline) has a modulus of 2,990-3,090 MPa and strength of 70-75 MPa (Ansys, Inc., 2025). For materials with similar values see Appendix E.5.

7.3 Tensile strength test

According to Instron & Thackeray (2026), tensile testing serves as a fundamental method for characterising a material's behaviour under tension. By subjecting a specimen to a controlled pulling force, this test quantifies the material's mechanical limits. The resulting data is critical for engineering applications, allowing designers to determine exactly how a material will perform in specific structural contexts.

7.3.1 Tensile strength test setup

For the tensile strength test, 11 samples were prepared following the ASTM D638 standardisation. While automated cutting methods are generally recommended for standardising specimen geometry, they were not feasible for this material. The available laser cutter would have melted the composite's PVC coating, which poses a severe health and safety risk due to the potential emission of toxic chlorine gas. Consequently, the specimens were manually cut using a band saw, with intricate cuts finalised using a utility knife. The specimens were cut to a dog bone with the dimensions seen in Figure 53.

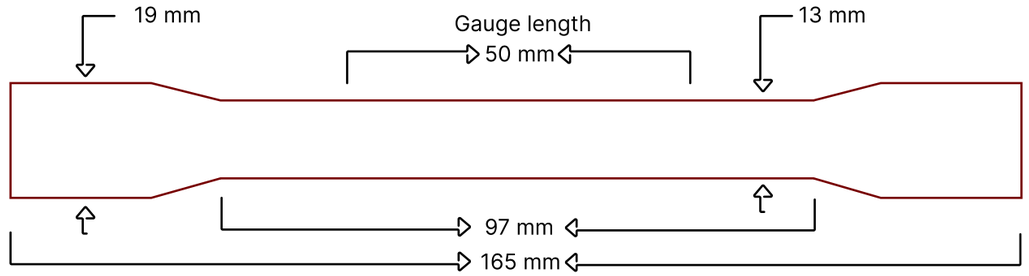


Figure 53. *Tensile strength test sample size*

For the final testing 11 specimens were prepared, their measurements are noted in Table 10. The setup of the instrument can be found in Figure 54, where the samples were each clamed in the centre. For further details about the set up reference Appendix E.6.

Table 10. *Tensile strength test sample measurements*

Value measured	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
Width 1	13.30	14.05	13.40	13.60	13.15	13.15	12.85	13.45	13.90	13.25	13.70
Width 2	13.35	13.45	13.15	13.05	13.30	13.50	13.15	13.40	13.65	13.25	13.15
Width 3	13.80	13.20	12.95	13.75	13.10	13.25	13.00	13.55	12.95	12.95	13.45
Width Avg. (w)	13.48	13.57	13.50	13.47	13.18	13.30	13.00	13.47	13.50	13.15	13.43
Thickness 1	3.30	3.00	3.20	3.50	3.15	3.25	3.40	3.45	3.00	3.15	3.60
Thickness 2	3.15	2.90	3.10	3.50	3.05	3.25	3.35	3.40	2.90	3.15	3.50
Thickness 3	3.10	2.85	3.10	3.70	3.10	3.30	3.40	3.35	3.10	3.15	3.45
Thickness Avg. (t)	3.18	2.92	3.13	3.57	3.09	3.27	3.38	3.40	3.00	3.15	3.52
Gauge length (Lo)	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00	50.00
Area (A=w*t)	42.92	39.57	42.30	48.03	40.78	43.45	43.98	45.79	40.50	41.42	47.24

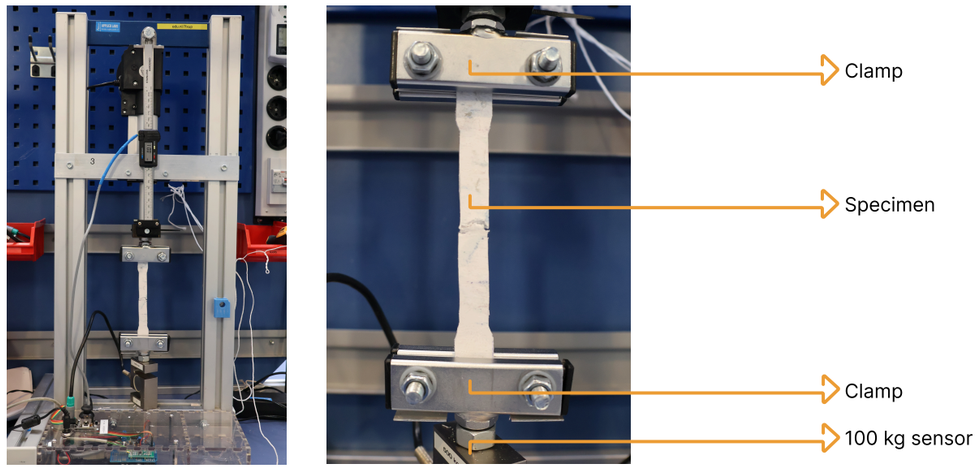


Figure 54. *Bending test setup*

7.3.2 Tensile strength test results

The tensile strength tests will give an indication of how much pulling force can be exerted till the material tears. Throughout the testing it became clear how the heterogeneous qualities of the material has a great affect on the strength of the material. Some of the material was also contaminated with a piece of rope and carton, which have drastic effects on the material qualities.

Eleven specimens were tested, where samples 2, 7 and 11 can not be used for their data as they failed at the 'shoulders', see Figure 55. Other samples also strayed from the expected failure locations, which would be the centre of the dog bone. In the cases of samples 3, 4, 5 and 6 this was due to a weak spot in the material.



Figure 55. *Specimens after tensile strength tests, failure locations highlighted*

Table 11. *Tensile strength test result values*

Value measured	Sample 1	Sample 3	Sample 4	Sample 5	Sample 6	Sample 8	Sample 9	Sample 10
Thickness Avg. (t)	3.18	3.13	3.57	3.09	3.27	3.40	3.00	3.15
Area	42.92	42.30	48.03	40.78	43.45	45.79	40.50	41.42
Max. extension	8.88	16.11	5.66	16.77	12.06	5.05	7.75	5.74
Max. load	193.67	237.99	177.27	267.07	236.14	218.54	217.25	211.71
Young's modulus	130.66	178.05	175.41	91.09	107.41	12.08	206.56	186.54
Max. stress (σ)	4.79	6.01	3.67	6.64	5.71	5.26	5.46	4.81
Max. strain (ε)	0.10	0.18	0.06	0.18	0.14	0.06	0.09	0.07
Yield strength	3.26	4.11	2.12	5.30	3.20	3.07	2.35	3.55

3

After the testing the data was analysed and used to make stress-strain graphs using the following formulas:

$$\text{Stress } (\sigma) = \frac{\text{force (N)}}{\text{area (mm}^2\text{)}}, \quad \text{Strain}(\varepsilon) = \frac{\text{change in extension}}{\text{initial gauge length (L0)}}$$

All stress-strain graphs can be found in Appendix E.7, four test results are discussed in this chapter. The initial slope of the graphs equals the young's modulus, see Table 11 for the results. The maximum stress equals the ultimate tensile strength. At the highest point of the initial slope, seen in Figure 56 at point A, is the yield strength. This indicates how much stress can be developed in the materials without causing plastic deformation.`

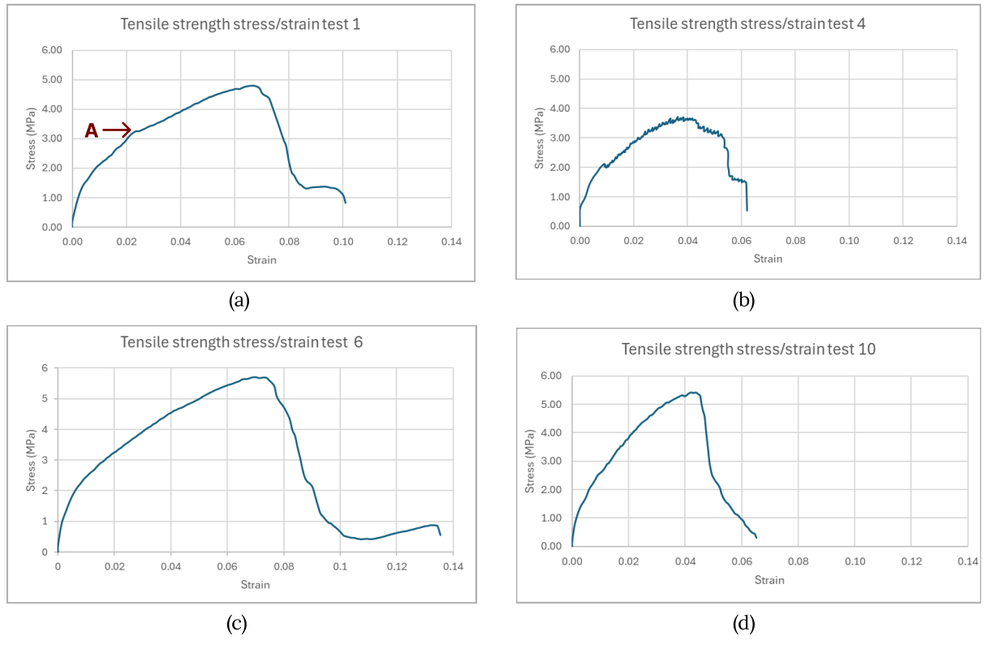


Figure 56. *Tensile strength tests 1, 4, 6 and 10 stress/strain graphs*

For the found values of the tensile strength test a comparison was done to find materials with similar properties, this list can be found in Appendix E.8.

7.4 Water absorption test

Understanding a composite material's porosity is vital for determining its suitability in wet environments, such as bathroom wall tiling or outdoor signage exposed to precipitation.

7.4.1 Water absorption test setup

During the water absorption test the standardisation ASTM D570 was used. Five samples were cut to have the dimensions seen in Figure 57, they were then sanded to make sure the edges were all equally smooth.

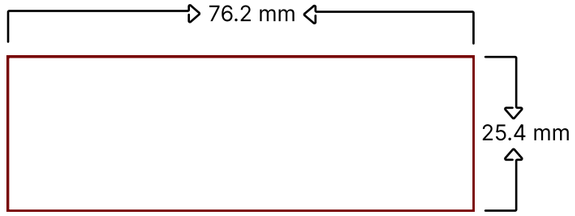


Figure 57. *Water absorption test sample size*

The exact measurements of all the samples can be found in Table 12, with area (A)=2(w*l)+2(l*t)+2(t*w). The samples were first weighed in their dry, room-temperature state. They were then fully immersed in water for a 24-hour period. A holder was printed to make sure that the samples stayed upright during submergent, see Figure 58. Upon removal, surface water was wiped away and the specimens were immediately weighed to determine the mass of the absorbed moisture as well as every 30 minutes for the next 3 hours afterwards.

Table 12. *Bending test sample measurements*

Value measured	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Width 1	23.90	24.00	23.95	24.00	23.30
Width 2	23.80	23.70	23.80	24.20	23.60
Width 3	23.45	23.70	23.60	24.30	23.70
Width Avg (w) [mm]	23.72	23.80	23.78	24.17	23.53
Length 1	73.40	73.35	73.10	73.35	73.10
Length 2	73.40	73.50	73.15	73.45	73.25
Length 3	73.20	73.70	73.10	73.50	72.95
Length Avg. (l) [mm]	73.33	73.52	73.12	73.43	73.10
Thickness 1	3.20	2.90	2.80	3.00	2.80
Thickness 2	3.20	2.90	2.80	2.95	2.85
Thickness 3	3.20	3.00	2.75	3.05	2.90
Thickness Avg. (t) [mm]	3.20	2.93	2.78	3.00	2.85
Area (A) [mm2]	1739.22	1749.70	1738.96	1774.64	1720.39
Initial weight [g]	7.41	5.37	5.29	5.33	5.17
Density [kg/m3]	1330	1050	1090	1000	1050



Figure 58. *3D printed sample holder*

7.4.2 Water absorption test results

The results for the water absorption test were not significant in change from dry to wet, meaning that the material is largely water resistant, see Table 13 for test data. The samples exhibited weight increases ranging from 0.40% up to 3.38% after 24 hours of immersion. While pure plastics like HDPE absorb virtually zero water (Ansys, Inc., 2025), the fibrous nature of the shredded PET banners likely creates microscopic channels within the panel, see Figure 59, that allow moisture intake. A maximum absorption of ~3.4% suggests that while the material is largely water-resistant, it is not entirely waterproof and may be susceptible to minor swelling or freeze-thaw damage if used outdoors without a sealed edge.

Table 13. *Bending test sample weight data*

Value measured (g)	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Dried weight	7.40	5.34	5.34	5.30	5.13
Room temp. weight	7.41	5.37	5.29	5.33	5.17
Wet (24h) weight	7.44	5.49	5.45	5.51	5.23
Weight difference (%)	0.40%	2.23%	3.02%	3.38%	1.16%
Drying 30 min	7.43	5.48	5.44	5.45	5.21
Drying 60 min	7.41	5.43	5.39	5.37	5.18
Drying 90 min	7.41	5.41	5.39	5.36	5.19
Drying 120 min	7.43	5.40	5.39	5.35	5.16
Drying 150 min	7.41	5.40	5.37	5.33	5.15
Drying 180 min	7.42	5.39	5.37	5.34	5.15

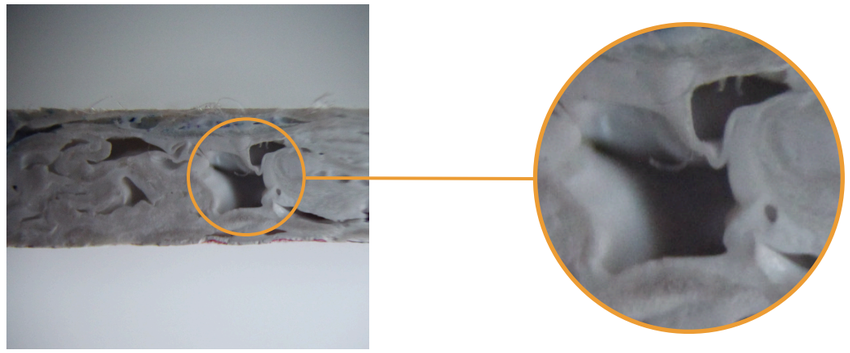


Figure 59. *Microscopic side view of Sign Again*

Another observation is that when the material is printed with a glossy ink, the material is ~28% heavier than Sign Again printed with mat ink. See Figure 60 where the samples are placed next to each other to compare their finish.

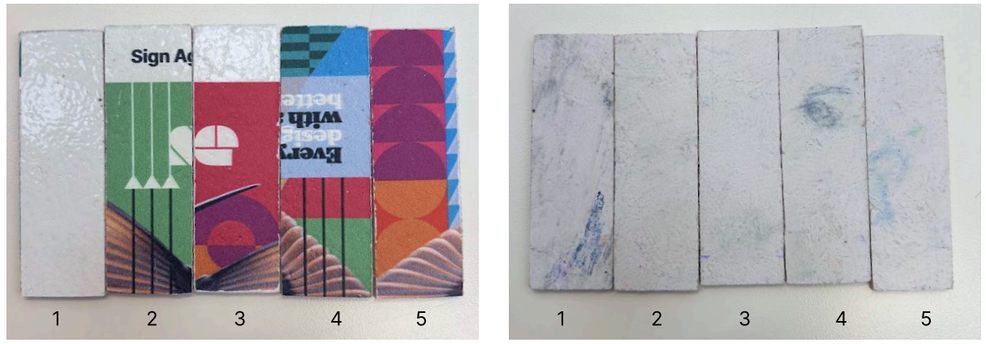


Figure 60. *Water absorption test samples*

7.5 Screw pull test

Sign Again might be used for wall tiling or signage, which is why a screw pull-out test is useful to determine how much force is required to pull a fastener out and to observe the resulting material damage.

It is important to note a limitation of this testing setup: the test isolates the screw while the surrounding material is rigidly secured by the testing jig. Under real world loading conditions, a localised pulling force could cause the surrounding flexible material to distort or tear alongside the screw, rather than resulting in a clean strip of the threads. The results might also look different if the sample were to be pulled off of the screw or if the screw was installed the other way around so that the head would have to be pulled through the material. For this project, only a screw withdrawal test was conducted and analysed.

7.5.1 Screw pull test setup

For the setup of the test a jig needed to be made so that the samples could lay horizontally with the screw sticking up vertically. The jig was made so that the bottom clamp could hold it and the sample could slide in securely with enough room for the screw. This ensured that the screw could be fixed to the top clamp and be pulled out vertically while the sample stayed in place. The screw was inserted 20 mm, measured from the bottom of the sample, in every sample and then loaded in the jig. See Figure 61 for a picture of this setup.

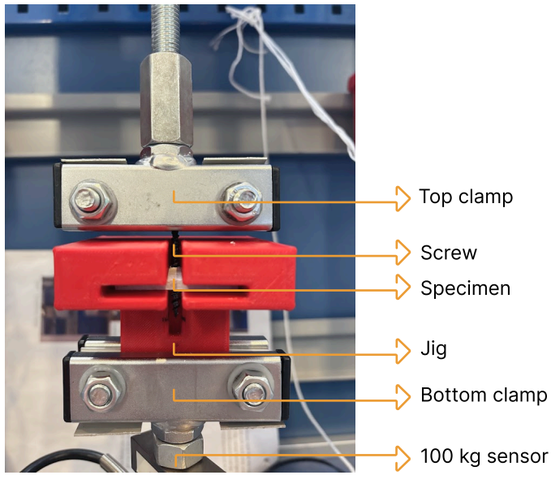


Figure 61. *Screw pull test set up*

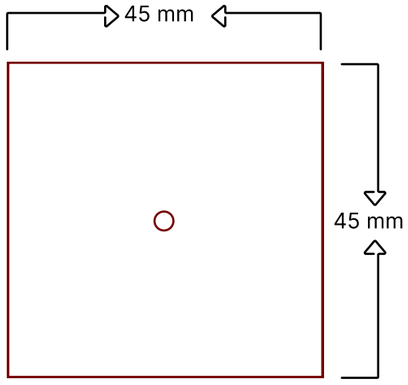


Figure 62. *Screw pull test sample size*

Six samples were prepared with the measurements found in Figure 62 and a 3 mm pilot hole was drilled into the centre of it to avoid damaging the sample while inserting the screw. The thicknesses of the samples can be found in Table 14.

Table 14. *Screw test result values*

Value measured	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Thickness	3.55	3.70	3.35	2.95	3.00	3.25

7.5.2 Screw pull test result

After conducting the screw pull-out test across six samples, the load-extension data was analysed to determine the maximum vertical force the material can withstand before fastener failure occurs. In screw withdrawal tests, there are typically three primary modes of failure: shear/stripping of the surrounding material or breakage of the fastener itself.

For the Sign Again material, visual inspection confirmed that the exclusive mode of failure across all six samples was stripping of the material, see Figure 63. As the vertical force exceeded the material's shear strength, the screw threads tore through the composite, often leaving visible shreds of PVC and PET embedded in the threads of the extracted screw (see Figure 64).

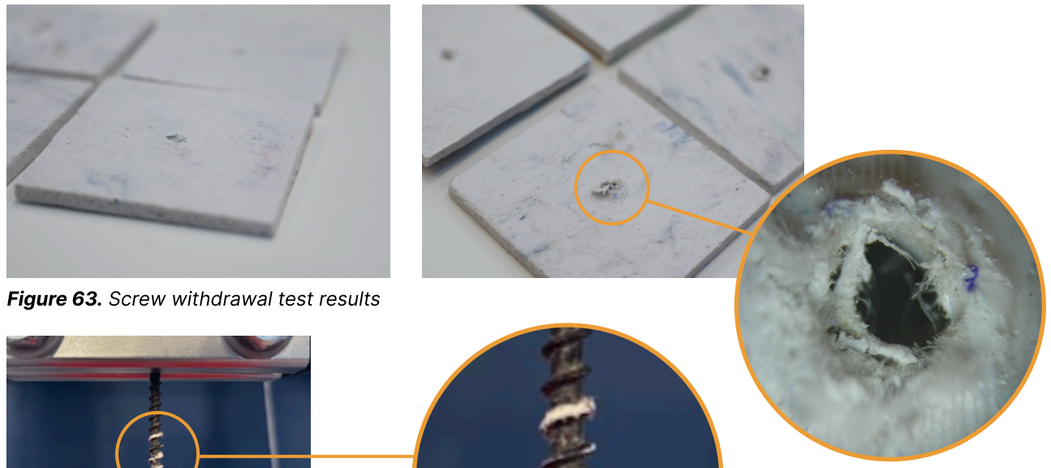


Figure 63. *Screw withdrawal test results*

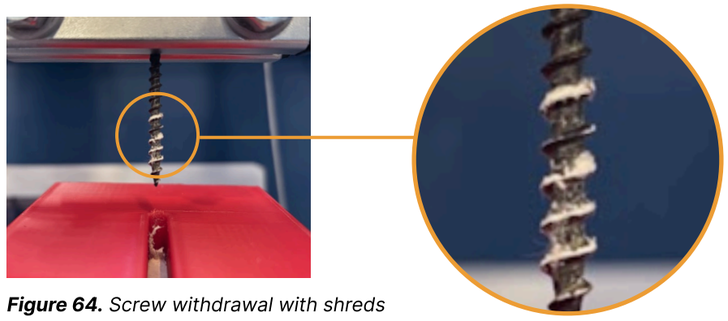


Figure 64. *Screw withdrawal with shreds*

The quantitative results (see Table 15) reveal a significant variance in the material's holding power. This broad range in pull-out strength, where the strongest sample withstood nearly three times the force of the weakest, highlights the heterogeneous nature of the recycled composite. Because the shredded banner fragments are thermally pressed rather than chemically homogenised, the internal density of the board varies. If a screw is driven into a dense, well-fused cluster of PET fibers, the pull-out resistance is high. Conversely, if the screw hits a localised weak spot or a pocket of less-fused PVC, it strips out at a much lower force. For the force-elongation graphs please refer to Appendix E.9.

Table 15. *Screw test result values*

Value measured	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Maximum load	590.16	534.42	734.66	343.81	261.67	578.18
Failure mode	Strip	Strip	Strip	Strip	Strip	Strip

From a design perspective, this unpredictability is the most critical takeaway. Because the material yields via thread stripping at highly variable loads, product designs (such as wall tiles or hanging signage) should not rely on high-tension, single-point screw connections. To prevent localised pull-out failures, future design interventions should distribute the mechanical load by using bolts with washers, threaded inserts or mounting channels instead of relying solely on the material's internal thread-holding capacity.

7.6 Shore test

A Shore test measures the hardness of a material, specifically its resistance to permanent indentation under a defined force. In the context of this research, evaluating the surface hardness of Sign Again is critical for determining its suitability for high-traffic applications, such as event flooring or protective tiling. By quantifying the material's tactile quality and surface resilience, this test provides essential data on how the recycled composite will respond to localised stress and everyday wear and tear compared to traditional virgin polymers.

7.6.1 Shore test setup

For the shore test five samples were prepared following the ASTM D2240 standardisation. See Figure 65 for the measurements of the samples, the dots indicating where the punctures have to made.

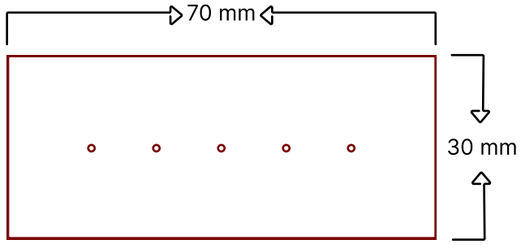


Figure 65. *Shore D test sample size*

The setup can be found in Figure 66, here a durometer type D was used for the testing. The tool was placed on top of a stack of 3 specimens as on layer alone is not thick enough by the requirements of the standardisation.



Figure 66. *Shore D test setup*

7.6.2 Shore test result

After conducting the Shore D hardness test across five samples (with five distinct indentations measured per sample), the results yielded an overall average hardness of 52.14 Shore D. The quantitative data (see Table 16) reveals a significant variance not only between the different samples but also across the surface of individual specimens. For an overview of materials with a similar shore D value see Appendix E.10.

Table 16. *Shore test hardness data*

Value measured	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Hardness 1	45	46	59	42	50.5
Hardness 2	45	48	49.5	49	56
Hardness 3	55	52	49	53	62
Hardness 4	55	57	44.5	53.5	61
Hardness 5	45	46	53	52	75.5
Avg. hardness/sample	49	49.8	51	49.9	61
Average hardness	52.14 Shore D				

This level of surface variance is a direct consequence of the material's heterogeneous, shredded composition. Unlike virgin plastics that offer a uniform molecular structure, Sign Again consists of fused fragments of flexible PVC and PET. The durometer's steel pin measures exactly where it lands; if the pin strikes a dense, melted cluster of PET fibers, it registers a much higher hardness (such as the 75.5 Shore D spike). Conversely, if it lands on a pocket of softer PVC coating or a microscopic internal void, the reading drops significantly. Figure 67 shows what the indentation left by the durometer looks like.

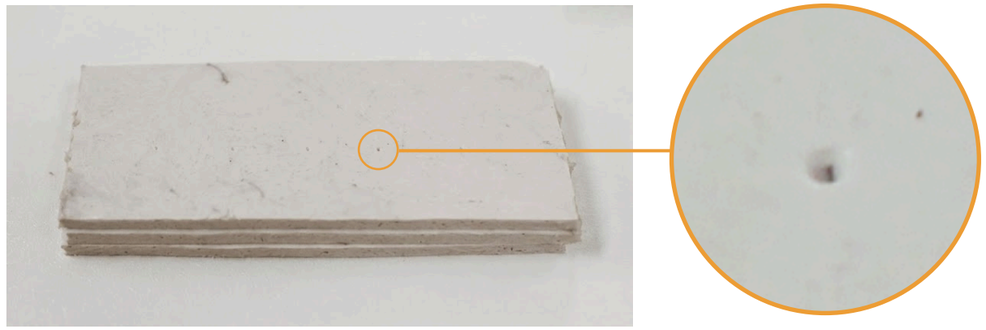


Figure 67. *Shore D test results*

Contextually, an average of 52.14 Shore D places Sign Again in the category of medium-hard, semi-rigid materials. For comparison, standard rigid PVC typically scores between 77–83 Shore D, while pure polypropylene scores around 64–68 Shore D (Ansys, Inc., 2025).

From a design and application standpoint, this lower hardness score is a double-edged sword. On one hand, it aligns with the high ductility observed in the bending tests; the material is highly impact-absorbent and will yield rather than shatter or crack when dropped or struck. On the other hand, a score of ~52 Shore D indicates that the material's surface is highly susceptible to scratching, gouging and localised indentation. Design interventions using this material, such as event flooring or reusable tiling, must account for this vulnerability to cosmetic surface wear over time, perhaps by embracing a speckled, textured aesthetic where scratches are less visibly disruptive.

7.7 Conclusion

During the material testing phase, a comprehensive profile of the Sign Again panel emerged by subjecting the material to various physical stresses and environmental conditions. The data gathered from the bending, tensile, water absorption, screw pull and hardness tests yielded several critical learnings. These insights highlight both the mechanical limitations of this recycled composite and its practical potential, dictating how it must be handled in future design interventions.

First of all the bending and tensile tests revealed that Sign Again is a highly flexible, yielding material. With a low flexural modulus (ranging between ~165–815 MPa) and the tendency to bend entirely without snapping, the material exhibits excellent impact absorption. However, its low yield and tensile strength mean it cannot bear heavy structural loads or withstand high-tension applications. Therefore, it is best suited for compressive or low-load applications, such as protective road plates, event flooring, siding or wall tiling, rather than weight-bearing structural frameworks.

Due to the board being manufactured by thermally pressing shredded PVC and PET banner fragments, its internal density and surface hardness (averaging 52.14 Shore D) are highly inconsistent. The screw pull-out tests demonstrated that this heterogeneity makes the material prone to unpredictable thread stripping under localised stress. Consequently, future product designs must avoid single-point, high-tension screw connections. Instead, mechanical loads must be distributed using bolts with washers, threaded inserts or interlocking modular joints that do not rely on the material's internal thread-holding capacity.

The water absorption test proved that Sign Again is largely water-resistant, making it a viable candidate for outdoor and wet environments. However, because the fibrous microscopic channels absorb a marginal amount of moisture (up to ~3.4%), the material is not completely waterproof. For permanent outdoor applications, designers must consider the potential for edge-swelling or freeze-thaw damage, potentially mitigating this by sealing exposed edges or designing products that allow for thermal expansion.

Ultimately, the material testing confirms that Sign Again cannot be treated as a one to one replacement for homogenous virgin plastics, wood or aluminum. It is a unique, monstrous hybrid composite. To successfully implement this material in a circular economy, designers must embrace its heavy, ductile and heterogeneous nature. This can be achieved by utilising it in modular, compressive and impact-resistant applications where its specific technical quirks become assets rather than liabilities.

Now with all these material properties gathered together, see Table 17, Sign Again can be compared to other materials with values within the same range this can be found in Appendix E.11 and E.12.

Table 17. *Material property overview Sign Again*

Material property	Sign Again
Price	4.29-6.14 EUR/kg
Density	1400 kg/m^3
Young's modulus	90-270 MPa
Tensile strength	2.00-5.30 MPa
Yield strength	3.50-6.75 MPa
Flexural modulus	160-815 Mpa
Flexural strength	20-30 MPa
Hardness - shore D	49-61
Water absorption	0.4-3.38 %

Chapter 8.

Design phase results

8.1 Design vision
- 8.1.1 Function
- 8.1.2 Target groups
- 8.1.3 Interested parties
- 8.1.4 Environment for use
- 8.1.5 Relation with other products
- 8.1.6 Distinguishing aspects

8.2 Ideation
- 8.2.1 How to's
- 8.2.2 Brainsotrm

8.3 The Sign Again guidebook
- 8.3.1 Structure
- 8.3.2 Visualisations

8.4 Guidebook validation
- 8.4.1 Comprehension of the problem and solution
- 8.4.2 Data visualisations and navigations
- 8.4.3 Missing information and practical application
- 8.4.4 Processing methods and physical interaction
- 8.4.5 Conclusion of validation

8.5 The Sign Again texture board

8. DESIGN DEVELOPMENT

8. Design development

This chapter details the exploration and development of the final design concept. Building upon the findings and problem statements established in the previous chapters, a design vision is formulated to guide the design process. Following this, the chapter explores the ideation phase, the iterative development of the guidebook and the subsequent validation of the concept. Finally, the chapter covers the development of the Sign Again texture board.

8.1 Design vision

Constructing a design vision (Van Boeijen et al., 2014) guides the final conceptualisation phase. A clear vision provides a structured context for the design, supporting the search for targeted ideas and ensuring the final concept remains aligned with the core problem. This subchapter explores the different aspects that shape the vision for this concept based on insights gathered during the research phase.

8.1.1 Function

The concept is designed to fulfill several core functions based on the programe of requirements set out in chapter 5.1.2.3 PoR concept:

- Inform:

Educate end-users about the material's physical properties and potential applications.

- Communicate:

Provide transparent information regarding the material's value chain and lifecycle.

- Engage:

Capture the user's interest and motivate them to learn about sustainable alternatives.

- Create awareness:

Highlight the current waste problem in the industry and present the proposed circular solution.

8.1.2 Target groups

The primary target group consists of professionals, manufactures and designers seeking to produce sustainable products using recycled materials. These individuals are actively exploring ways to lower their environmental impact and require accessible, clear yet in depth insights into the technical properties of the material and how it can be applied across different contexts.

A secondary target group includes the end-clients in industries where Sign Again is currently applied, such as tiling, temporary flooring, panel signage as well as potential future product lines. Furthermore, recycling companies form a part of the target audience. As the demand for recyclate grows, they must keep up with production. For this group, smooth logistical coordination and excellent stakeholder communication are essential.

8.1.3 Interested parties

Other stakeholders include print companies and the clients who purchase traditional signage. Print and sign companies need to understand the concept's business value so they can integrate it into their operations and steer their customers toward sustainable alternatives. The end-buyers must be informed about the environmental impact of their purchases to shift their behaviour and drive demand for circular options.

8.1.4 Environment for use

The concept will be used to inform anyone interested in learning about alternatives to virgin PVC banners and how these linear materials can be recycled. To expand its reach, the concept needs to function in both physical and digital procurement environments.

8.1.5 Relation with other products

To be effective, the concept must captivate users, entice them to read the information and persuade them to take the sustainable route. This means the design competes with the concise, available information and standard specification sheets that customers typically encounter when purchasing traditional signage online.

8.1.6 Distinguishing aspects

To stand out, the concept must attract attention and engage the audience. It needs to project trustworthiness, transparency and completeness, while challenging the user to step out of their habitual linear purchasing patterns and adopt circular behaviours.

8.2 Ideation

During the conceptualisation phase, time was dedicated to iterate and explore diverse methods for solving the defined problem.

8.2.1 How to's

By framing the problem statement in the form of a "How to..." question, the design challenge becomes easier to answer. A list of relevant "how-to" questions scoping the project can be found in Appendix F.1. The primary guiding question became: "How to communicate information to raise awareness and potentially change and maintain people's behaviour to be more sustainable?".

A difficulty in this transition is that a lack of change is often rooted in ingrained habits, established social norms, perceived inconvenience and a lack of emotional connection to the environmental problem. Educating people with facts alone is rarely enough to induce change. Instead, the goal is designing for change, creating an intervention that encourages users to adopt and maintain new behaviours. To achieve this, the design will aim to be based on several behavioural psychology principles (The Behavioural Insights Team, 2017):

1. Make it clear and easy

The tool must explain how people can make a change, rather than presenting them with just the why.

2. Make is social and emotional

The narrative should emphasise positive behaviours and frame the transition in terms of what users lose by sticking to the linear model, rather than just what they gain.

3. Make is a habit

The design must incorporate feedback loops and act as a prompt at the point of decision-making (e.g., procurement).

By applying these principles, the tool encourages an identity shift. This ensures that the concept will not be viewed as an isolated product, but rather as an intervention point designed to trigger awareness and support the adoption of circular concepts along the industry timeline.

To further guide the specific design elements, the following problem scopes were identified:

- How can the value chain be informed about the realities of the current system versus the circular alternative?
- How can companies and customers be encouraged to prioritise value over the lowest price when purchasing?
- How can decision makers be enabled to navigate the complexities of sustainability without feeling overwhelmed?
- How can recycled materials be made more attractive and viable than virgin materials?
- How can single-use purchasing behaviours be discouraged through better product positioning?

8.2.2 Brainstorm

Through illustrative brainstorming (see Figure 68), various mediums were explored to determine the best way to capture and present this data visually. Ideas ranged from online digital platforms and apps to videography, physical playbooks, manuals and flyering campaigns. It became apparent that because technical information needed to be conveyed to professionals, a transient medium (like a short video or flyer) would be less effective. Ultimately, a short guidebook format was selected, as it balances the need to display complex data with an accessible, narrative-driven layout.

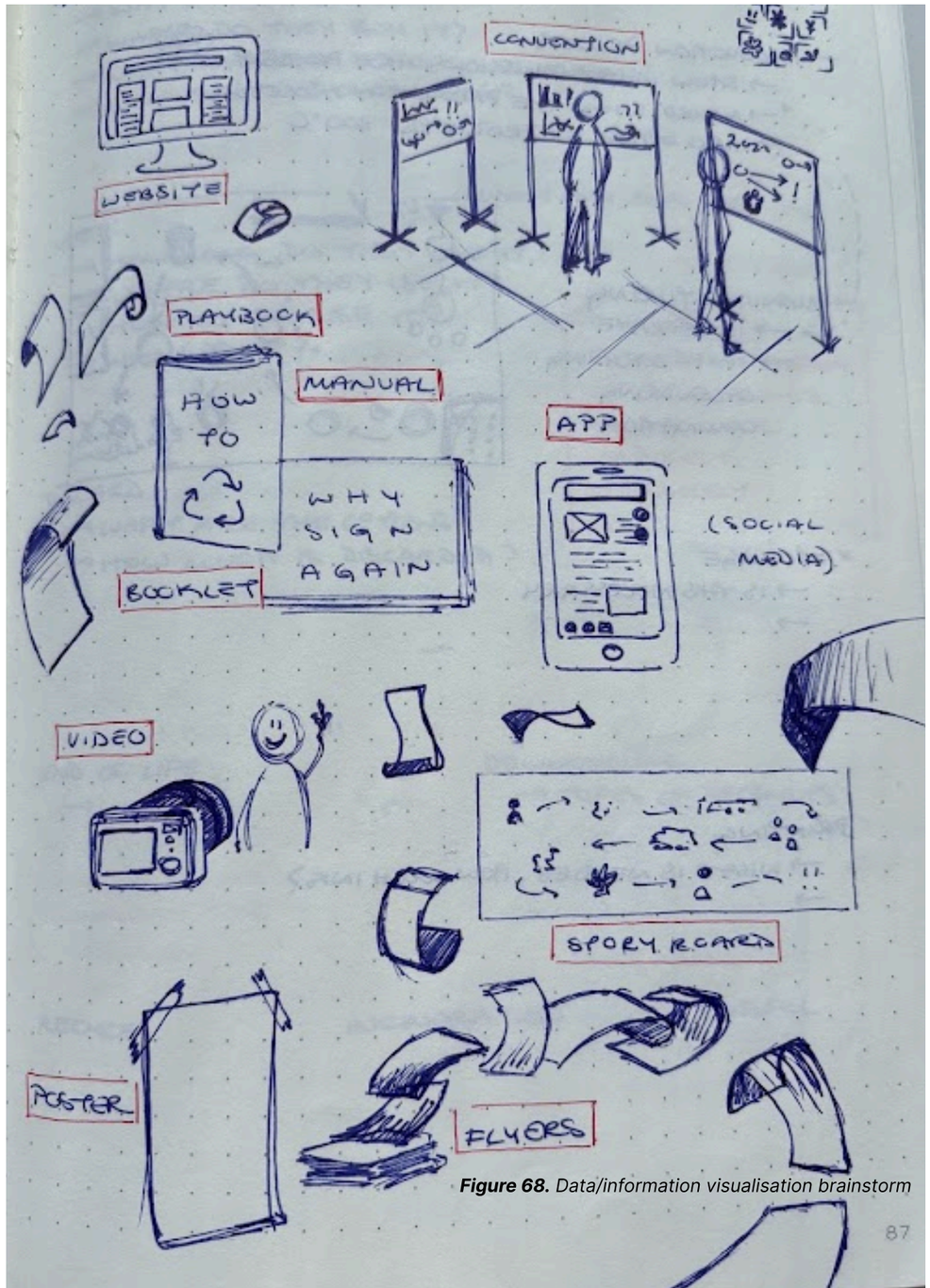


Figure 68. *Data/information visualisation brainstorm*

8.3 Guidebook

The guidebook entails essentially the most important findings of the project. It guides the reader from the problem to the solution till the possible impact that can be made through different decision making.

8.3.1 Structure

To give the reader some structure while reading, a why what how order was used to move from the problem towards the solution and conclusion:
Why should you read this?
Why does the system need to change?
What is a solution to move towards a circular economy?
What is Sign Again?
How does Sign Again compare?
How can Sign Again be manipulated?
How can Sign Again be recycled?
The use of colour was also chosen to help the reader know when a topic would change.

8.3.2 Visualisation

Keeping the user engaged throughout the guidebook is important, a way this was done was by adding the most important take aways in text balloons. The reader can then skim the guidebook and still understand the overall message. Also, where possible or neccesary, icons and images were used to not overcrowd pages with text only. The main design challenge, however, was to visualise the material testing data in a clear and digestible manner.

Initially, standard tables were used (see Figure 69), but they proved to be too dense for quick comparison. Through rounds of peer feedback (involving both students and industry colleagues), it became clear that users wanted to see all comparative data for a single property at a glance. This led to a shift away from standard tables toward a slider graphic, where material properties were mapped along a continuous horizontal axis.

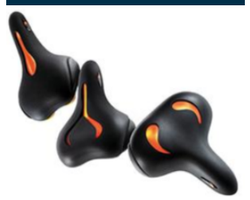
	Sign Again	PVC	Polyurethane rubber
			
Properties.			
Price	4.29-6.14 EUR/kg	1.19-1.64 EUR/kg	1.52-1.94 EUR/kg
Density	1400 kg/m^3	1290-1460 kg/m^3	1190-1210 kg/m^3
Young's modulus	90-270 MPa	2200-3100 MPa	2.5-30 MPa
Yield strength	2-5.3 MPa	37.6-45.5 MPa	40-51 MPa
Tensile strength	3.5-6.75 MPa	38-46 MPa	40-51 MPa
Flexural modulus	160-815 Mpa	2300-2960 MPa	2.5-30 MPA
Flexural strength	20-30 MPa	65-81 MPa	65-81.4 MPa
Hardness - shore D	49-61	77-83	12-41
Water absorption	0.4-3.38 %	0.04-0.4 %	0.2-0.22 %

Figure 69. *Table format of material data*

After testing how to visualise data when values and ranges overlapped closely, a streamlined visual style was established that placed the numerical data directly above the material bars on the axis. While the data remained dense, an inherent quality of a technical datasheet, this format made it easier to digest. Figure 70 shows how this horizontal graphic also went through different iterations, again based on peer feedback.

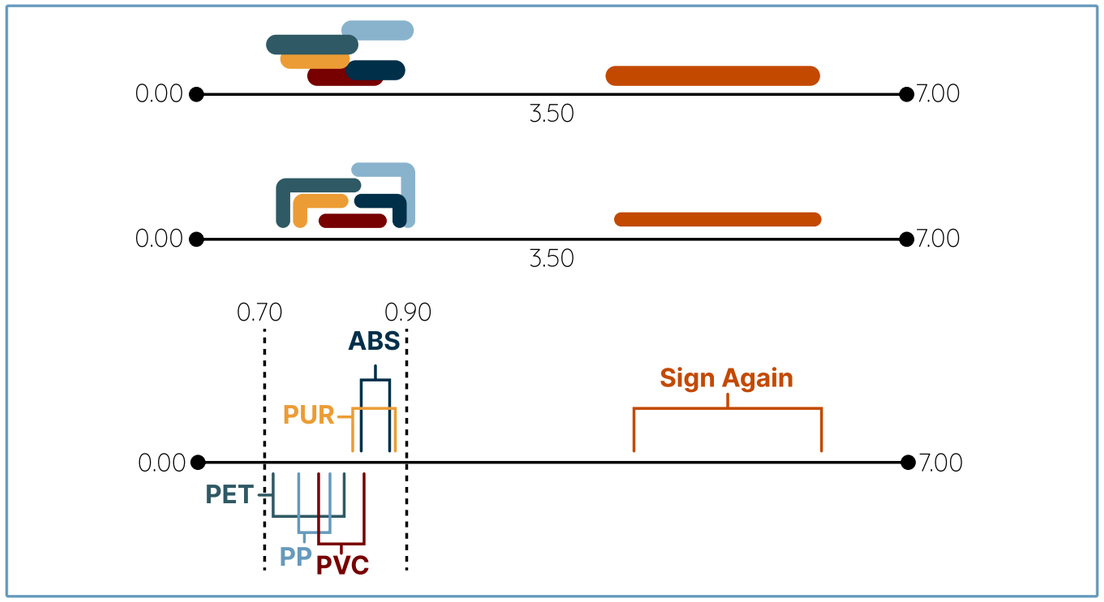


Figure 70. *Slider format of material data*

After completing a rough draft, the guidebook was reviewed by a UX expert at Horizonteer, leading to several refinements before final printing for the validation sessions:

- Icons were grounded with grey background planes to improve legibility.
- Margins and white space were increased to prevent visual fatigue.
- Text-heavy pages were made more visual and more pull-quotes were added to break up the reading experience.
- The "Avoid" processing methods were given distinct visual styling to ensure they stood out.

After these changes the guidebook was made to adhere to the printing requirements, eg adjusted margins and colours.

8.4 Guidebook validation

To ensure the Sign Again guidebook communicated its intended message and met the practical needs of its target audience, a validation phase was conducted. This involved a series of online feedback sessions with 8 people accompanied by a structured online questionnaire filled in by 13 respondents. The validation group consisted of professionals with backgrounds in Industrial Design Engineering, averaging three to four years of industry experience. The feedback gathered provided insights into the tool's comprehensibility, visual layout and overall persuasiveness.

8.4.1 Comprehension of the problem and solution

The guidebook communicated the core systemic issues of the linear print and sign industry. Respondents rated their understanding of the problem well (scoring an average of 6.38 out of 7), grasping that mixed-material PVC banners are incinerated due to differing melting points. The proposed solution was also well-received (6.46 out of 7), with participants understanding that Sign Again bypasses material separation by thermally pressing shredded waste into a new recyclate.

Actionable takeaway
To emphasise urgency, respondents recommended incorporating specific CO^2 emission reduction figures and stating the scale of the current problem using relatable metrics (e.g., total tons of PVC wasted annually) rather than just percentages.

8.4.2 Data visualisation and navigation

The validation of the data visualisation yielded positive results regarding its intuitiveness (6.31 out of 7). Respondents praised the visual comparisons and the clear use of colour coding.

Actionable takeaway
To improve accessibility, respondents recommended increasing visual white space to reduce crowding, re-evaluating font thickness and colour contrast (especially white text on colourful headers) for visually impaired users and cleaning up unnecessary decimal points on data labels.

8.4.3 Missing information and practical application

When asked what was missing, a thematic consensus emerged around the need for quantitative sustainability metrics and practical context. Users noted that CO^2 metrics are needed for translating the material's benefits into corporate sustainability reports.

Actionable takeaway
Respondents recommended adding an inspiration page featuring photographs of the material applied in real world contexts (e.g., event flooring, wayfinding signage). They also suggested adding specific data regarding print adhesion and UV stability depending on the field of application.

8.2.4 Processing methods and physical interaction

The processing guidelines were generally clear, but friction points were identified regarding the distinction between recommended methods (CNC/drilling) and discouraged methods (electric sawing).

Actionable takeaway
The guidebook should state why certain tools are bad (e.g., friction-induced heat generation) rather than just listing them.

When reviewing physical properties where Sign Again scores lower than virgin PVC (like yield strength), respondents agreed that touching a physical sample remains a step before specifying the material. The digital guidebook alone cannot replace the tactile validation required by designers.

8.2.5 Conclusion of validation

The validation sessions confirmed that the guidebook's most convincing arguments are the extension of the material's lifetime and the direct displacement of virgin plastics. Overall, respondents indicated a willingness to recommend or specify Sign Again based on the tool (an average score of 5.69 out of 7). By implementing the suggested refinements, adding quantitative metrics, increasing visual whitespace and clarifying the final call to action (e.g., linking the QR code to ordering a physical sample), the guidebook can transition into an effective B2B procurement asset.



Figure 71. *Validation sessions*

8.5 Texture board

Recycled composites possess different mechanical properties and surface aesthetics compared to virgin plastics, digital data alone often fails to bridge the tactile gap required for user adoption. As highlighted by the guidebook validation forms, being able to physically feel the material is a step for designers before they are more willing to specify it for a project. During the validation phase, respondents reported a lower likelihood of recommending the material to clients based solely on digital information.

To address these uncertainties, a physical Texture Board was developed alongside the guidebook. Embracing a 'design by doing' approach, the board serves as a tangible companion piece that creates a physical experience for the target group, giving them a better understanding of the material's potential and real world behaviour. By allowing users to interact directly with the composite feeling its weight, assessing its rigidity and examining its speckled surface finish, the board grounds the abstract data from the guidebook in reality. This physical interaction demystifies the recycled material, builds trust in its structural integrity, and gives stakeholders a clearer understanding of its practical applications.

To start of the conceptualisation phase for the texture board some inspiration was taken during some desktop research. Figure 72 shows some of the images which inspired the the prototyping phase.



Figure 72. *Inspiration pictures (Morby, 2016; Matter Atelier, 2026)*

The prototyping process started with a loose set of requirements of what elements needed to be present on the board. The most important elements which had to be included were:

- The list of Sign Again's properties
- The comparison of materials with similar properties
- The comparison of materials within similar industries
- Processing methods; electric saw, guillotine, box cutter, drill, nails, screws, sandpaper and PVC glue

Paper sketches were made to get a general idea of the layout which evolved to printing the layout on paper to a rough 1:1 scale, see Figure 73. This was then prototyped in 3D with MDF pieces seen in Figure 74. Finally, the exact locations of all the elements were decided and visualised in Illustrator, see Appendix F.2 for the file which was sent to the laser cutter. The material used was a 9 mm thick plywood board, 700 x 650 mm.



Figure 73. *Paper prototype*

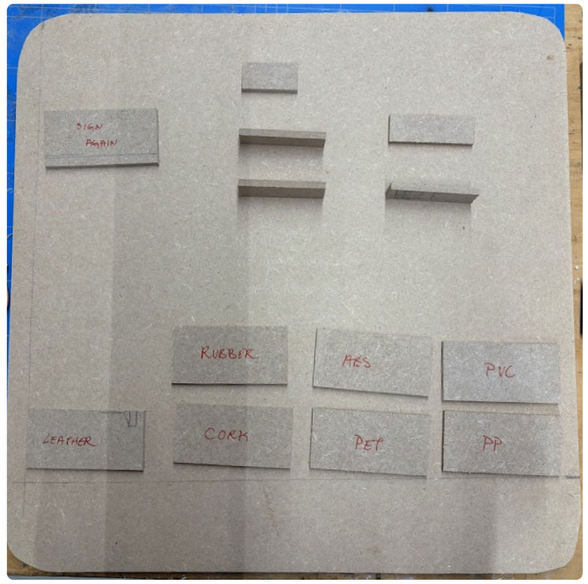


Figure 74. *MDF prototype*

Next, all the brackets which would hold the pieces of material were modeled in Solidworks and consequently 3D printed in two colours; the bracket in white and the titles in black for a high contrast. These brackets also went through some iterations to make sure that the sample of materials was clearly visible, this applied in particular to the processing method samples as the manipulation to the material needs to be highlighted.

Behind the material samples, located on the lower half of the board, there was room to add some further information about the material. Different options were played around with and eventually it was settled on some additional information to the content of the guidebook; for what can the material be used. Simple icons were used to illustrate what these functions would be such as tiling, medical or signage.



Figure 75. *Laser cut texture board and guidebook holder*

The material samples to be compared with Sign Again sourced online. These were rubber, cork, leather, PP, PVC, PET, ABS and PET. The remaining materials found in the guidebook could not easily be bought in small quantities, as the board only required a sample of 50 x 100 x 3 mm. Lastly, the Sign Again pieces were prepared which involved cutting pieces to size, drilling holes of various sizes, sawing, sanding and so on. This can all be found on the final texture board.

As a final touch, a booklet holder was designed to be attached to the side of the board, see Figure 75. In the case of this setup going to a convention or something similar, the two can be kept together and this makes it clear to the user that the guidebook and the texture board go together. One of the holders is for the English version and the other is for the Dutch version of the guidebook. This decision ensued from one of the validation sessions, a client of Horizonteer mentioned that their own clients are 70% Dutch. They explained that a translation of the guidebook would be very valuable to the company.



Figure 76. *Preparing samples for the texture board*



Figure 77. *All parts prepared, cut and printed ready to be assembled*

Chapter 9.

Results design phase

9.1 Strategic roadmap
9.2 The Sign Again guidebook
9.3 The Sign Again texture board
9.4 Implementation plan
9.4.1 Launch and market awareness
9.4.2 Strategic scaling
9.4.3 Systemic transformation
9.4.4 Business positioning and opportunities

9. RESULTS DESIGN PHASE

9. Results design phase

This chapter presents the finalised design results, which concludes the design phase. It entails the explanation of the solutions and some recommendations. The final outcome is a strategic roadmap which outlines the future vision and what steps need to be taken based on relevant trends. A guidebook was designed to bring more technical knowledge about Sign Again to the system and give designers a better idea of what the material is and how it can be used. Lastly, a texture board was made with the intent to give the end user a tactile experience of the material.

9.1 Strategic roadmap

As one of the three components of the final results, a strategic roadmap was developed to guide the print and sign industry's transition away from single-use virgin PVC. The roadmap contextualises Sign Again and the designed guidebook in combination with the texture board within a broader systemic timeline. It outlines actionable milestones divided into three distinct phases: short-term validation, mid-term scaling and long-term systemic transition. Ultimately the goal is to achieve a more CO^2 neutral value chain by 2045 by following the steps layed out.

Phase 1 - system validation and logistical proof

This short term phase of 5 years (2025-2030) focusses on establishing a foundation for the circular system and capturing early market adopters. Here the roadmap targets three areas:

- Systemic logistics: Leveraging the immediate financial pressure of rising disposal costs and incineration taxes, companies are incentivised to initiate localised micro take-back schemes for post-consumer banners.
- Awareness and demand: The guidebook is launched to capture market demand from clients actively seeking sustainable alternatives. It provides the transparent storytelling required to shift initial purchasing behaviours.
- Technological validation: Digital fabrication (such as CNC-routing) is utilised to design and manufacture flat-pack pilot products. This step validates the mechanical viability of the Sign Again recyclate for rigid applications, proving that the material can be successfully reprocessed.

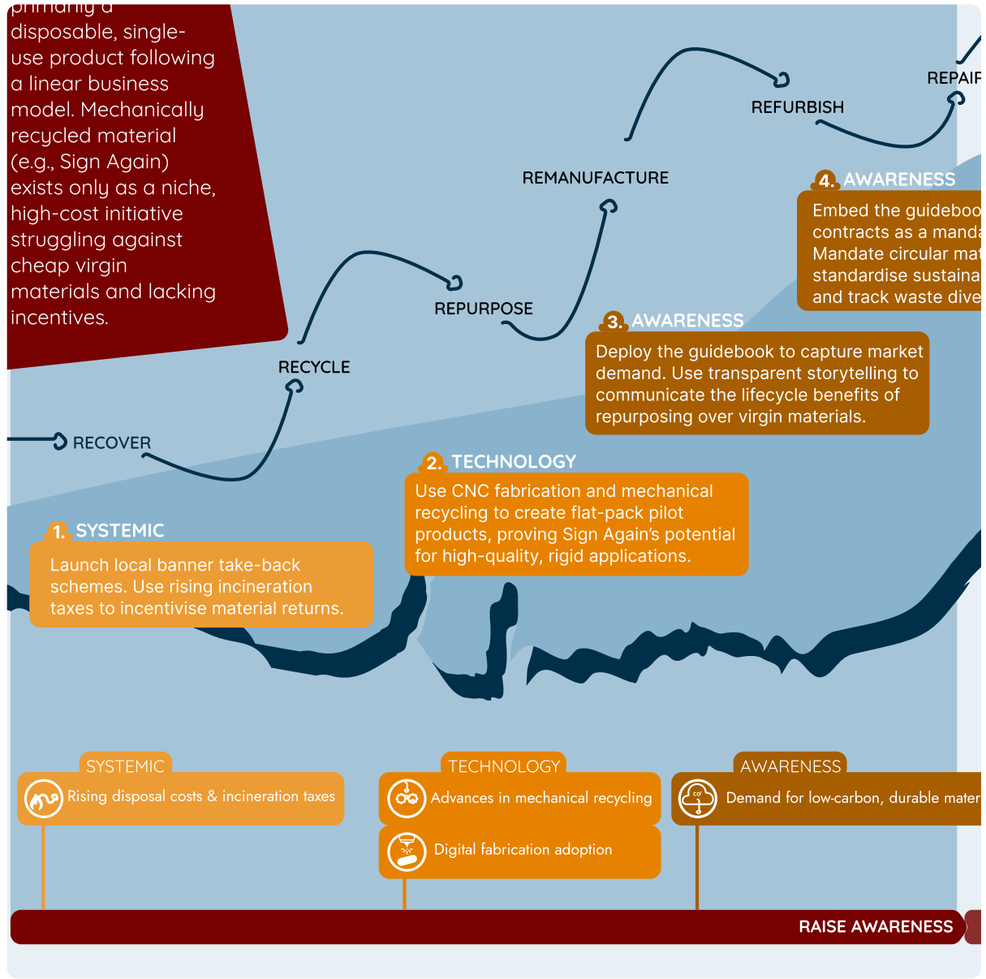


Figure 78. *Strategic roadmap phase 1*

Phase 2 – scaling, standardisation and competitive advantage
The mid term phase lasts 10 years where the objective shifts toward formalising the circular business model and expanding the infrastructure to handle larger volumes of material.

- Awareness to procurement: As sustainable buying habits normalise, the guidebook evolves into a mandatory procurement asset embedded in B2B contracts.
- Product Service Systems (PSS): Technological development aligns with the implementation of Product-Service Systems. Design efforts move away from single-use signs and focus entirely on modular, reusable applications (such as temporary event flooring) that guarantee multiple lifecycles before requiring reprocessing.
- Scaling take-back systems: To handle the increased volume of returned banners, take-back logistics are secured through formal leasing contracts. Partnerships with local social enterprises are integrated to manage the labour-intensive pre-treatment steps, including sorting, cleaning and shredding.

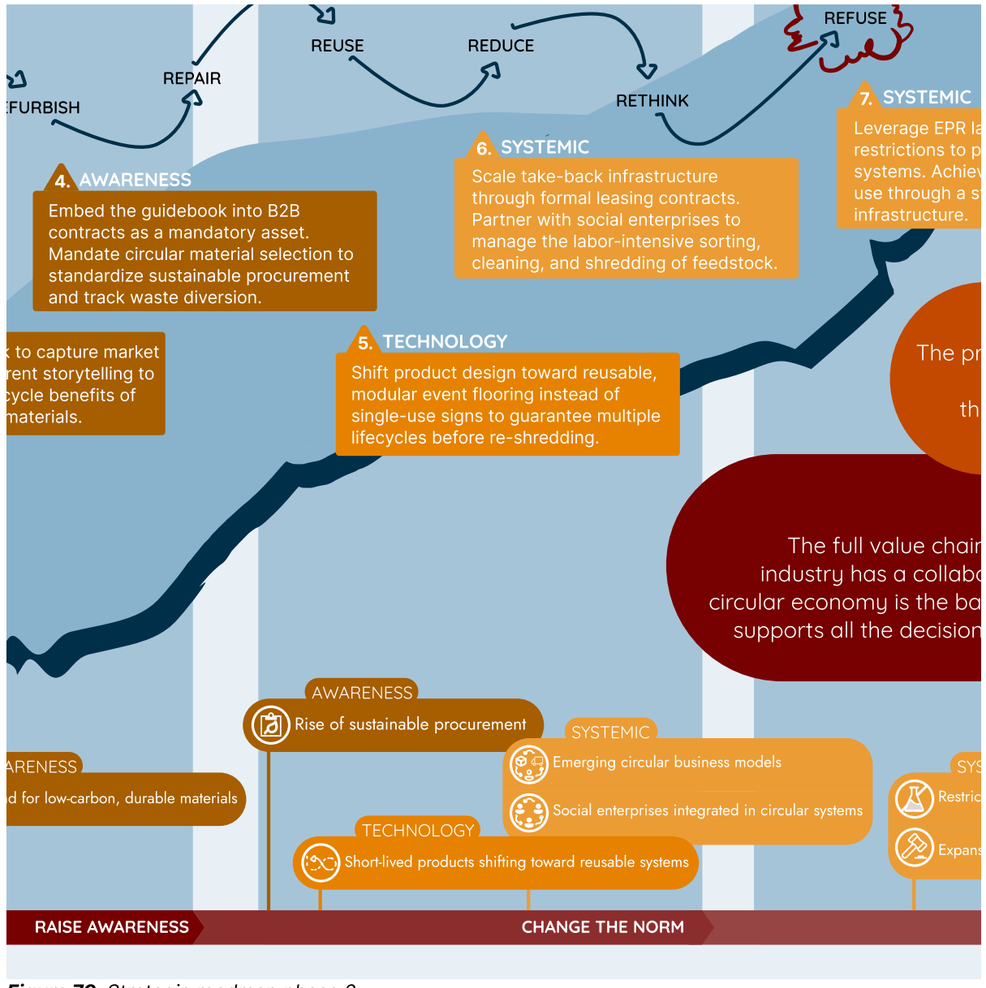


Figure 79. *Strategic roadmap phase 2*

Phase 3 - complete systemic transition
The final phase of the roadmap, 20 years later in 2045, relies on macro-level systemic drivers to eliminate the linear model entirely.

- Policy compliance: Expanding the EPR laws and European Union restrictions on hazardous additives force the final phase-out of monstrous hybrids like virgin PVC banners.
- Displacing virgin plastics: The standardised circular infrastructure scales to a point where it seamlessly absorbs all material flows, indefinitely displacing virgin plastics in favour of true circular alternatives.

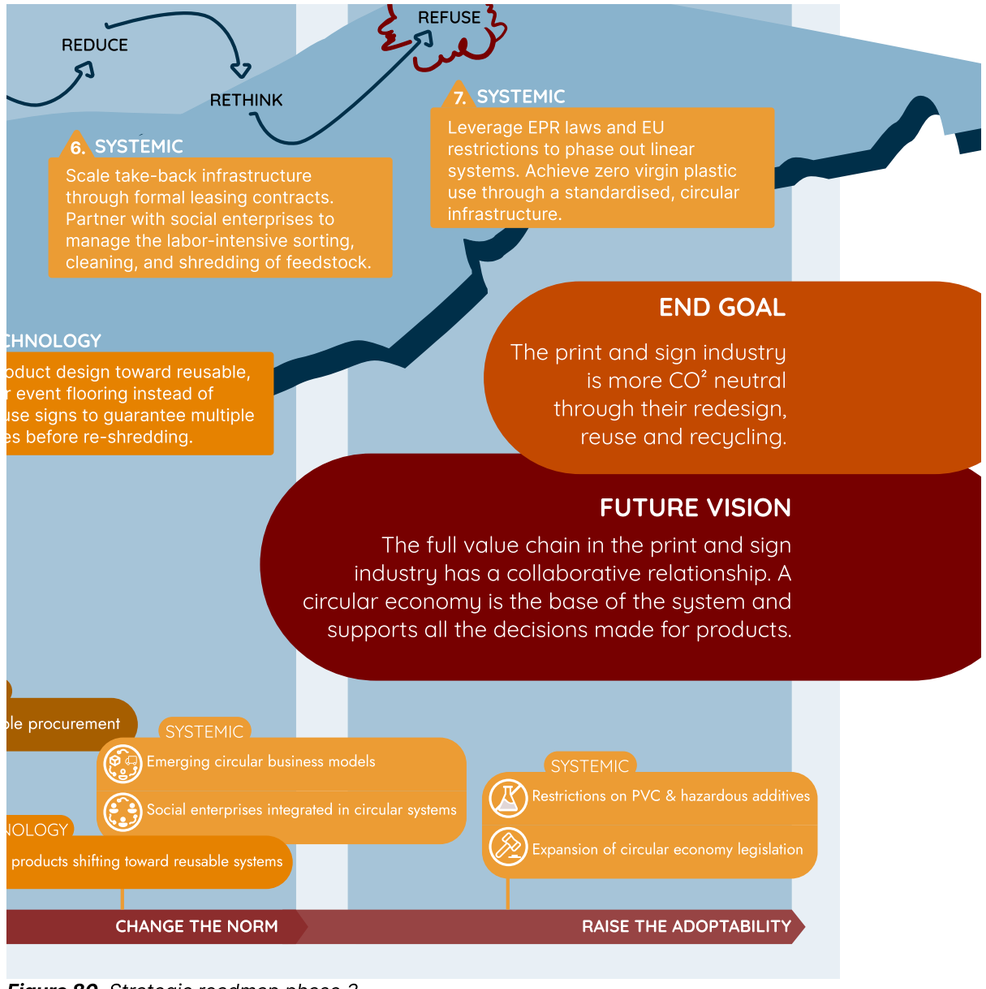


Figure 80. *Strategic roadmap phase 3*

End goal realisation
By executing these steps, the full value chain of the print and sign industry transitions into a collaborative relationship. A circular economy becomes the base of the system, supporting all product decisions and resulting in an industry that becomes more and more CO^2-neutral through continuous redesign, reuse and recycling.

STRATEGIC ROADMAP FOR A CIRCULAR TRANSITION WITH SIGN AGAIN

NOW 2025

PVC banners are primarily a disposable, single-use product following a linear business model. Mechanically recycled material (e.g., Sign Again) exists only as a niche, high-cost initiative struggling against cheap virgin materials and lacking incentives.

2030

SHORT-TERM [5 YEARS]

A functional pilot system is established that consistently collects and transports post-consumer PVC banners. Initial material processing is validated to demonstrate technical and mechanical viability for material reuse, leaving room to explore alternative applications and securing the commitment of key stakeholders.

Goal: System validation and logistical proof

2035

MID-TERM [10 YEARS]

Standardised recycled materials rival virgin plastics through formal take-back schemes. Integrated circular models ensure a reliable feedstock, while campaigns actively phase out temporary virgin banners.

Goal: Scaling, standardisation and competitive advantage

2045

LONG-TERM [20 YEARS]

A regenerative European system indefinitely displaces virgin plastics and meets EU legislation, ultimately phasing out monstrous hybrids in favour of true circular alternatives.

Goal: Complete systemic transition and policy compliance

RECOVER
RECYCLE
REPURPOSE
REMANUFACTURE
REFURBISH
REPAIR
REUSE
REDUCE
RETHINK
REFUSE

1. SYSTEMIC
Launch local banner take-back schemes. Use rising incineration taxes to incentivise material returns.

2. TECHNOLOGY
Use CNC fabrication and mechanical recycling to create flat-pack pilot products, proving Sign Again's potential for high-quality, rigid applications.

3. AWARENESS
Deploy the guidebook to capture market demand. Use transparent storytelling to communicate the lifecycle benefits of repurposing over virgin materials.

4. AWARENESS
Embed the guidebook into B2B contracts as a mandatory asset. Mandate circular material selection to standardise sustainable procurement and track waste diversion.

5. TECHNOLOGY
Shift product design toward reusable, modular event flooring instead of single-use signs to guarantee multiple lifecycles before re-shredding.

6. SYSTEMIC
Scale take-back infrastructure through formal leasing contracts. Partner with social enterprises to manage the labor-intensive sorting, cleaning, and shredding of feedstock.

7. SYSTEMIC
Leverage EPR laws and EU restrictions to phase out linear systems. Achieve zero virgin plastic use through a standardised, circular infrastructure.

END GOAL

The print and sign industry is more CO^2 neutral through their redesign, reuse and recycling.

FUTURE VISION

The full value chain in the print and sign industry has a collaborative relationship. A circular economy is the base of the system and supports all the decisions made for products.

SYSTEMIC — Rising disposal costs & incineration taxes
TECHNOLOGY — Advances in mechanical recycling; Digital fabrication adoption
AWARENESS — Demand for low-carbon, durable materials
AWARENESS — Rise of sustainable procurement
SYSTEMIC — Emerging circular business models; Social enterprises integrated in circular systems
TECHNOLOGY — Short-lived products shifting toward reusable systems
SYSTEMIC — Restrictions on PVC & hazardous additives; Expansion of circular economy legislation

RAISE AWARENESS | CHANGE THE NORM | RAISE THE ADOPTABILITY

Figure 81. *Final strategic roadmap*

9.2 The Sign Again guidebook

The primary design intervention developed in this research is the Sign Again guidebook, formatted as a B2B procurement booklet. This tool translates the technical data and systemic insights gathered during the research phase into an accessible format for industry professionals, designers, and print-and-sign clients. Its objective is to bridge the gap between environmental awareness and actionable procurement by providing the specific data required to justify transitioning away from virgin PVC.

Structure

The guidebook is structured to guide the user through a logical transition from problem identification to material application. It begins by explicitly defining the core systemic issue, the linear lifecycle of composite PVC banners, supported by quantitative metrics such as annual waste volumes and disposal trajectories. Following this, it introduces the Sign Again recyclate as a circular alternative, outlining its manufacturing process and position within the waste hierarchy.



Figure 82. *Reading through the guidebook*

Data visualisation

To communicate the technical specifications of the material without causing cognitive overload, standard data tables were replaced with a custom visual layout. Material properties, such as density, tensile strength, and flexural modulus, are mapped along continuous horizontal slider graphics. This specific design choice allows users to directly compare the mechanical performance of the Sign Again composite against traditional virgin plastics at a glance, facilitating informed decision-making.

Practical application

To support the physical implementation of the material, the guidebook features a dedicated section on processing guidelines. It describes recommended fabrication methods (such as CNC routing and drilling) from discouraged techniques (such as electric sawing). Based on validation feedback, the text explains the underlying mechanical reasoning for these constraints, noting that high-speed friction generates heat that damages the recyclate. Additionally, the tool provides photographs of real world applications, contextualising the material in practice.

Integration

By combining technical property data with concrete sustainability metrics, the guidebook functions as a procurement asset. It addresses the current information deficit in the market, supplying decision-makers with the concrete evidence needed to select circular materials over established linear options.

The final version of the Sign Again guidebook can be found in Figures 84-87.



Figure 83. *Guidebook comparison spread laying on top of Sign Again panels*

ENG

The SIGN AGAIN guidebook.



PVC banner shreds thermally pressed into a recyclate panel.

By Amber Markus
Made possible by TU Delft and Horizonteer

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Printed in the Netherlands

This guidebook is designed to provide accurate and authoritative information on the print and sign industry. It is spread with the intention to convince people to take the sustainable route when given the choice. The author will not be held responsible for the consequences of any actions and/or decisions taken as a result of any information given or recommendations made.

Table of content

Introduction _____ 1
The core problem _____ 2
The solution _____ 3
Sign Again _____ 4-7
Materials with similar properties comparison _____ 8-10
Materials within similar industries comparison _____ 11-13
Sign Again processing methods _____ 14-15
The end of life _____ 16-17

Introduction

Why should you read this?

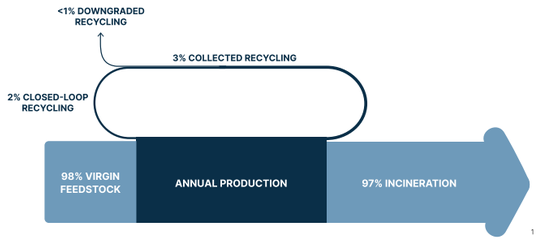
Welcome to the Sign Again guidebook. Currently, the print and sign industry operates on a highly linear, disposable model where materials are used briefly and subsequently discarded. With upcoming EU Circular Economy legislation and Extended Producer Responsibility (EPR) mandates, this 'take-make-use-dispose' approach will soon become a costly financial and regulatory liability.

This guidebook is designed for people who are interested in using recycled material to produce sustainable products and who want to future-proof their operations. It provides transparent, tested data on Sign Again, a recycled composite material made from PVC banner waste. By reading this, you will understand how to practically work with this unique material, how it compares to virgin plastics and how you can integrate it into profitable, circular business models that actively reduce your carbon footprint.

The core problem

Why does the system need to change?

The material loop is barely closed due to a fragmented stakeholder system. The figure below shows how much material is lost in the loop, there is lack of a take-bake system and incentive for producers, manufactures and consumers alike to make sure the materials go back in the system for reuse.



1

Today, 97% of PVC banners end up in incinerators after a single use. Why is this number so high? Traditional banners are a monstrous hybrid material, a permanent fusion of polyvinyl chloride (PVC) coating and polyester (PET) woven fibers. Due to a thermal mismatch, PVC melts at 170–190°C while PET requires 260–280°C, makes them chemically incompatible for high-quality recycling. So, these materials cannot be economically separated using standard recycling methods, they are rejected by traditional recycling facilities and sent to be burned or end up in a landfill. As disposal costs and incineration taxes continue to rise, the industry desperately needs a viable alternative to keep these valuable plastics in use.



2

1 Material flow of PVC banners (based on Ellen McArthur Foundation, 2019)
2 Image of banner (FSEID, 2025

Figure 84. *Guidebook front cover till page 2*

The solution

What is a solution to move towards a circular economy?

Instead of attempting the nearly impossible task of separating the PVC from the PET, the Sign Again process embraces the hybrid nature of the waste. The used banners are collected, shredded into coarse fragments and thermally pressed into heavy yet flexible composite panels. By turning lightweight banners into dense panels, we capture kilograms of waste rather than grams (2.8-5.6 kg/m²).

PVC BANNER



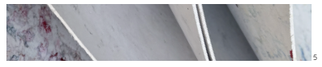
3

SHREDDING



4

THERMAL PRESS



5

FLOORING TILING SIGNAGE

However, achieving a true circular economy requires more than just new materials, it requires new business models. To maximise the value of Sign Again, we recommend transitioning to Product-Service Systems (PSS). Instead of simply selling a sign or a floor panel to be eventually thrown away, manufacturers can lease modular event flooring, reusable road plates or temporary signage. By incorporating a take-back scheme into the service, the material is guaranteed to return to the manufacturer, completely closing the loop.

3 PVC banner (FIXME source)
4 Shredded PVC banner (image from author)
5 Sign Again panels (image from author)

Sign Again

What is Sign Again?

Sign Again is not a one-to-one replacement for virgin plastics, it is a unique composite with distinct mechanical behaviours and properties. Here is what the technical data means for your designs:

Properties.		
Price	4.29-6.14	EUR/kg
Density	1400	kg/m^3
Young's modulus	90-270	MPa
Yield strength	2.00-5.30	MPa
Tensile strength	3.50-6.75	MPa
Flexural modulus	160-815	Mpa
Flexural strength	20-30	MPa
Hardness - shore D	49-61	
Water absorption	0.4-3.38	%



Price (4.29 – 6.14 EUR/kg)
This sits at a mid to high range price point. However, this price reflects true cost of local mechanical recycling and a reduced carbon footprint.
Design implication: Justify the cost by leaning into the material's circular storytelling and the upcoming taxes on virgin plastics.

Density (1400 kg/m³)
Sign Again is a heavy, dense composite. It outweighs many lightweight plastics and natural materials.
Design implication: Use this weight as an asset. It is ideal for ground-based, stable applications like event flooring, heavy tiling, road plates or wall tiling where weight provides stability

'Sign Again is best suited for compressive or low-load applications, such as protective road plates, event flooring, siding or wall tiling, rather than weight-bearing structural frameworks.'

Sign Again

Young's Modulus (90 – 270 MPa)
This measures how stiff the material is when pulled. A low score indicates that the material is highly elastic and will stretch significantly before it permanently deforms.

Yield Strength (2.00 – 5.30 MPa)
This is the exact amount of stress it takes to permanently warp the material. Because this number is relatively low, Sign Again yields easily under pulling forces.

Tensile Strength (3.50 – 6.75 MPa)
This is the maximum pulling force the material can take before it physically tears.
Design implication for these three: Because of its shredded, fibrous composition, the material tears under heavy tension rather than holding firm. Do not use this material for hanging heavy structural loads or in high-tension applications.

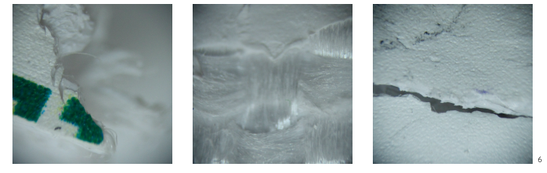
'Designers must embrace its heavy, ductile and heterogeneous nature. This can be achieved by utilising it in modular, compressive and impact-resistant applications where its specific technical quirks become assets rather than liabilities.'

Flexural Modulus (160 – 815 MPa)
This represents the material's resistance to bending. This range means the material is highly ductile, it bends deeply under a load instead of snapping or shattering.

Flexural Strength (20 – 30 MPa)
The maximum bending stress it can take before structural failure.
Design implication for both: The material has excellent impact absorption. If it is dropped or struck, it will yield rather than break. It performs exceptionally well in compressive, flat applications (like flooring) rather than spanning wide, unsupported gaps where it might sag.

Sign Again

Hardness (49 – 61 Shore D)
This classifies Sign Again as a medium-hard, semi-rigid material.
Design implication: While its softness prevents it from shattering, it makes the surface susceptible to cosmetic scratching, gouging and localised indentation. Product designs should embrace its speckled, textured aesthetic, which helps hide surface wear over time.



6

Water Absorption (0.4 – 3.38%)
The material is largely water-resistant, making it viable for wet environments. However, because the pressed shredded fibers create microscopic internal channels, it is not 100% waterproof.
Design implication: For permanent outdoor installations, seal the exposed edges to prevent moisture from seeping in and causing freeze-thaw damage.



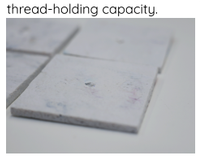
7

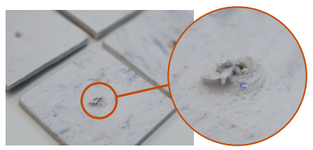
6 Microscopic images of Sign Again (image from author)
7 Microscopic images of side view of Sign Again (image from author)

Figure 85. *Guidebook pages 3-6*

Sign Again

Screw pull (260 - 735 N / material strip)
Tests show that the primary failure mode is material stripping, where the screw tears through the composite rather than snapping the fastener. This is due to the material's heterogeneous density.
Design implication: Designs must avoid single-point, high-tension screw connections. Instead, mechanical loads must be distributed using bolts with washers, threaded inserts or interlocking modular joints that do not rely on the material's internal thread-holding capacity.





[8]

> 'Designers must consider the potential for edge-swelling or freese-thaw damage, potentially mitigating this by sealing exposed edges or designing products that allow for thermal expansion.'

When evaluated against traditional virgin materials, Sign Again occupies a unique niche in the market. It is significantly stiffer and more resilient than flexible elastomers like butyl rubber or leather, yet remains far more yielding and flexible than highly rigid structural plastics such as ABS or pure PET.

Beyond its mechanical performance, the material offers a distinct aesthetic advantage. Unlike the uniform, pristine finish of virgin plastics, Sign Again features a speckled, textured appearance derived from shredded coloured banners. This characteristic serves a practical function by naturally camouflaging surface wear; to further minimise the visibility of scratches, the application of a matte or embossed finish is recommended. In a market where clients actively seek 'visible circular stories,' this recycled aesthetic serves as a powerful, transparent communication tool to showcase a brand's commitment to sustainability. On the other hand, the material can be easily printed on top of to without the visual texture obstructing the new design.

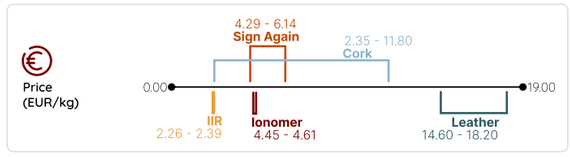
8 Images of Sign Again before and after a screw pull test (image from author)

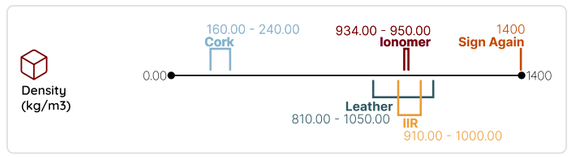
Materials with similar properties comparison

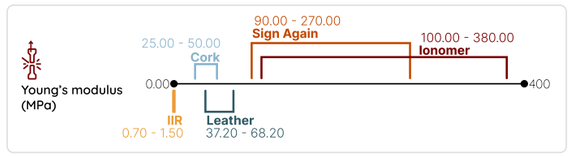
How does Sign Again compare?

There are some materials which have some overlapping material properties. This is based on the Young's modulus, yield strength and tensile strength. These can be found below.

- Sign Again
- Ionomer
- IIR (isobutylene isoprene rubber)
- Cork
- Leather





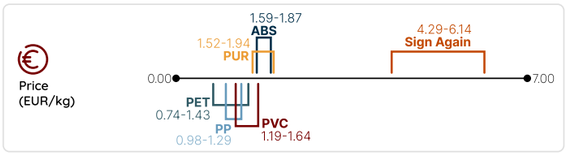


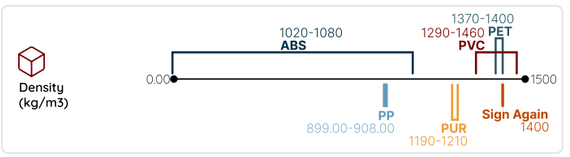
Materials within similar industries comparison

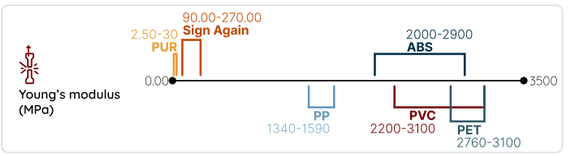
How does Sign Again compare?

Sign Again is compared to materials which are used in the industries where the composite is already on the market. Here we look at (temporary) flooring, wall tiling and signage.

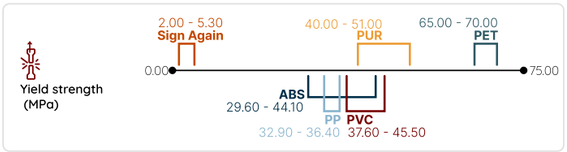
- Sign Again
- PVC
- PUR (polyurethane)
- ABS
- PET (polyethylene)
- PP (polypropylene)

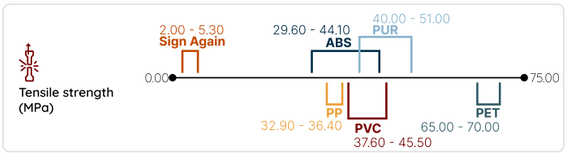


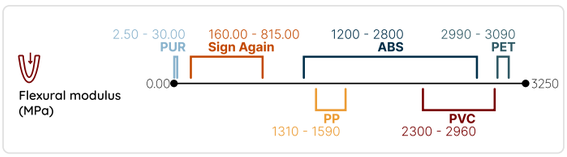


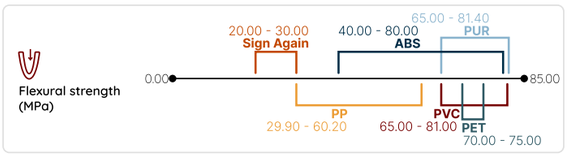


Materials within similar industries comparison

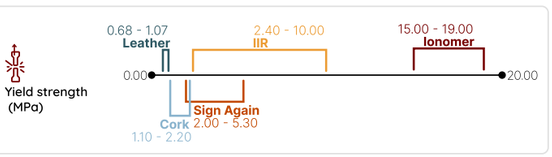


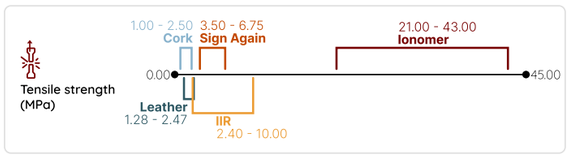


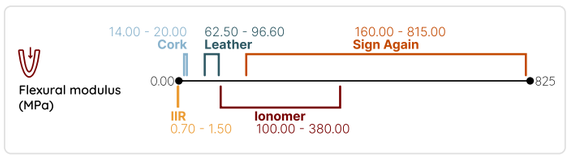


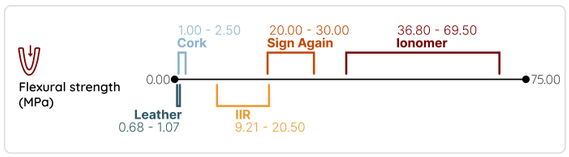


Materials with similar properties comparison

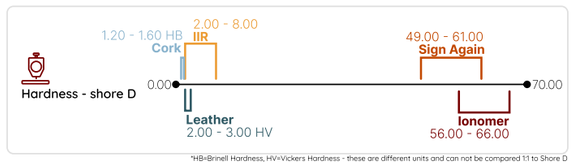




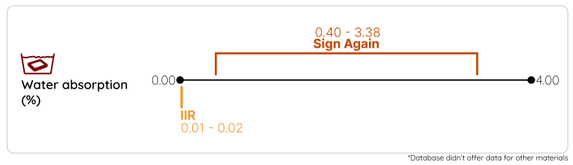




Materials with similar properties comparison



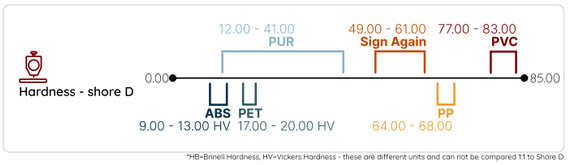
*HB=Brinell Hardness, HV=Vickers Hardness - these are different units and can not be compared 1:1 to Shore D



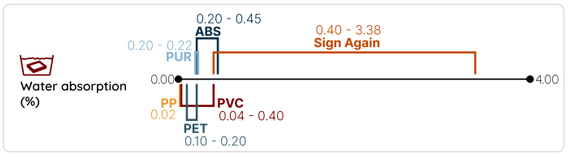
*Database didn't offer data for other materials

Figure 86. *Guidebook pages 7-10*

Materials within similar industries comparison



*HB=Brinell Hardness, HV=Vickers Hardness - these are different units and can not be compared 1:1 to Shore D



Sign Again processing methods

Altering.

Working with a recycled composite requires specific handling to ensure safety and durability. To get the panel material into smaller pieces there are a few recommendations for an accurate and clean cut found below.



Clean it up.

If the edges are rough from cutting the material, there are some strategies to get it more smooth through the use of sandpaper or a CNC machine.



Fastening.

To connect pieces of Sign Again to each other there are some ways to do this effectively, like with screws or PVC glue. The panel material can also be attached to other surfaces using screws, nails or tracks.



Watch out.

Any saw blades or large drill bits will create very rough edges, however, it is efficient in cutting the material.



Figure 87. *Guidebook pages 11-14*

Sign Again processing methods

Avoid.
Avoid anything that significantly heats the material while processing it, to minimise toxic gas emissions, such as laser cutters. An other option would be to have very good airflow and filters capturing the emissions.



Applications.
Now you are probably wondering how this recyclate can actually be applied in real world applications. Below are some examples of what is already produced from Sign Again, but there are still many options to explore and experiment with.

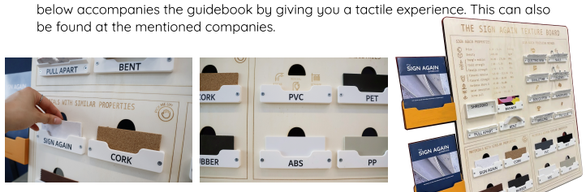
WAY FINDING FLOORING TILING DIVIDERS



9

AND MORE..

To get a better idea of what the material feels like and how it compares to the materials mentioned in this guidebook get in contact with Horizonteer, Igepa or other companies carrying Sign Again and ask for a sample. The texture board below accompanies the guidebook by giving you a tactile experience. This can also be found at the mentioned companies.

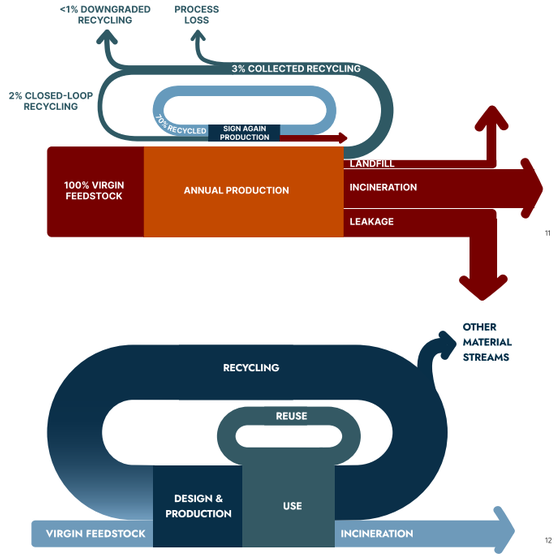


10

9 Images of current applications of Sign Again (FIXME source)
10 The Sign Again texture board to give the user a tactile experience (images from author)

The end of life

How can Sign Again be recycled?
The lifecycle of Sign Again does not end after one application. The sheet material can be mechanically recycled up to 7 times while retaining its core properties. At the end of a product's functional lifespan, whether it is a scratched floor panel or an outdated sign, the material must be returned through a designated take-back scheme. Upon return, the old panels are simply re-shredded and pressed back into brand new boards. By participating in this reverse logistics system, you ensure that this material lives its full potential and achieving a regenerative circular economy within the print and sign industry.



11

12

11 Material flow of PVC banners into Sign Again loop (inspired by Ellen McArthur Foundation, 2019)
12 Circular economy ideal to be achieved in nearby future (inspired by Ellen McArthur Foundation, 2019)

The end of life

As is clear from the images on the previous page, Sign Again is not the almighty solution to reach a zero waste system. PVC needs to be phased out throughout the years as there is no way to sustainably process it. It is necessary to use mono material products to recycle better or move to materials which are biodegradable.

Circular checklist:

VALUE IS LOST

- Refuse
  Do not buy virgin material if you get the choice.
- Rethink
  Transition leasing panels rather than buying them to guarantee recovery.
- Reduce
  Optimise your project layout to minimise off-cut waste and maximise material yield. To keep your product in use longer, you can seal all exposed edges against the weather and choose textured finishes that mask surface scratches from foot traffic.
- Reuse
  Avoid permanent adhesives and instead use bolts and washers so that you can easily disassemble the installation and use the panels again for your next project.
- Recycle
  At the very end of the product's life make sure your panels are returned to be shredded into a brand-new generation of Sign Again.
- Recover
  If the material becomes too degraded or contaminated after multiple lifecycles to be shredded again, ensure it is sent to a controlled waste-to-energy incineration facility rather than a landfill.

By following these steps, your are personally ensuring that your project never contributes to the 97% incineration rate, but instead stays within a regenerative loop. For more information go the the Sign Again website or get in contact with the collaborating partner Horizonteer.

signagain.com **horizonteer.nl**

The
SIGN AGAIN
guidebook.

Figure 87. *Guidebook page 15 till back cover*



Figure 88. *The Sign Again guidebook in front of the texture board*

9.3 The Sign Again texture board

The aim of creating a texture board is to give the target group, among others technical signage makers, a better understanding of the materials through a physical interaction instead of solely a textual and visual information.

Alongside the guidebook, a physical texture board was developed as a complementary concept. The validation phase indicated that while data visualisation informs initial procurement decisions, tactile interaction with a new material remains a required step for designers before specification. Because recycled composites possess different surface aesthetics and mechanical properties compared to virgin plastics, digital data alone is often insufficient to secure user adoption.

Structure and material mapping

The texture board is designed to physically map the material transition while summarising key technical data. It guides the user through the recycling process by presenting three distinct physical stages:

1. Linear: A raw piece of a standard virgin PVC banner, representing the current industry baseline.
2. Shreds: A sample of the shredded banner material, illustrating the intermediate pre-treatment phase.
3. Circular: A sample of the final Sign Again composite board, allowing users to feel the end product.

Integration of technical data

To bridge the tactile experience with the necessary technical specifications, the board integrates specific elements directly from the guidebook. The surface of the board displays the material properties overview and the specific processing methods so that any positive or negative finishes left on the material are evident.

Functional role

A dedicated holder on the side of the board contains the printed guidebook, merging the physical exploration of the material with the comprehensive data required for procurement. By allowing stakeholders to physically assess the composite's weight, rigidity and speckled surface finish while simultaneously reviewing its performance metrics, the texture board targets the uncertainties identified during the validation phase and supports the practical adoption of the recycled material.



Figure 89. *Close up of the materials with similar properties section*



Figure 90. *Close up of material being taken out of bracket*



Figure 91. *Close up of PVC taken out of bracket*



Figure 92. *Full texture board with guidebook holders*



Figure 93. *Complete texture board with highlighted areas*

9.4 Implementation plan

The implementation plan serves as a strategic guide for Horizonteer and its partners to integrate the Sign Again guidebook and Texture Board into the market. It follows a phased approach, based on a business model canvas (Horizonteer, 2026) which can be found in Appendix G.1 and G.2, aligned with the research findings, moving from immediate awareness to long-term systemic change.

9.4.1 Launch and market awareness

The immediate objective is to dismantle the information and tactile gaps that prevent stakeholders from adopting recycled composites.

Deployment of the Texture Board:
Horizonteer's clients will distribute the Texture Board to key decision-makers in the print and sign industry, including sustainability officers and creative directors. This physical boundary object acts as a tool in sales meetings to establish trust in the material's structural integrity.

Digital integration of the Guidebook:
The Guidebook will be launched as a companion digital asset. It will be integrated into the procurement portals of print shops and marketing agencies, providing the technical proof required to justify the switch from virgin PVC.

Marketing campaign:
A targeted B2B campaign focusing on the narrative of "capturing kilograms instead of grams." The messaging will emphasize that while perfect recycling is a future goal, Sign Again offers a pragmatic, immediate solution for existing waste.

9.4.2 Strategic scaling

This phase shifts from individual sales to systemic partnerships, focusing on high-volume waste producers.

The RAI Amsterdam Pilot: As identified in the research, large-scale venues like RAI Amsterdam are vital potential partners. The implementation involves integrating the Guidebook's standards into the RAI's official procurement guidelines. By mandating circular material selection for event signage and flooring, the RAI can leverage its market power to heavily encourage suppliers to adopt the Sign Again loop.



Figure 94. *Holding guidebook*



Figure 94. *Reading guidebook*

Implementation of PSS:
Print and Sign companies will transition from selling panels to selling visibility. In this model, banners are leased to events; after the event, the system manages the return and repurpose into Sign Again panels, which are then leased back to the venue as modular event flooring or wayfinding structures. This keeps material ownership within a controlled loop.

9.4.3 Systemic transformation

The final phase focuses on moving up the R-ladder and achieving policy compliance.

Advocacy for policy change:
Utilising the data collected through the Guidebook, Horizonteer and its partners will advocate for EPR and taxes on virgin PVC to raise the 'economic floor', making circular materials the financially logical choice.

Transition to refusal (mono-materials):
As the industry matures, the roadmap guides stakeholders toward phase 3: the refusal of PVC/PET hybrids in favor of 100% mono-materials. In this stage, the Sign Again infrastructure serves as the 'backstop' for existing waste while new designs prioritise high-quality, closed-loop recycling.

9.4.4 Business positioning and opportunities

For Horizonteer, these outputs represent a transition from service provider to circularity advisor.

Positioning:
Horizonteer positions itself as the 'trust-broker' in the value chain. The Guidebook and Texture Board are not just products, they are assets that validate the circularity of their consulting services.

Opportunities:
There is significant potential to scale the Sign Again model into other heavy-duty products where the material's weight is a functional benefit, such as parasol bases or traffic infrastructure. By providing the data (Guidebook) and the experience (Texture Board), Horizonteer creates a repeatable framework for other monstrous hybrids in the industry.

Chapter 10.

Conclusion

10.1 Answering the research questions
- 10.1.1 Positioning the concepts
- 10.1.2 Sing Again - not the final destination
- 10.1.3 Policy, behaviour and responsibility
- 10.1.4 Strategic scaling

10.2 Answering the research questions
10.3 Literature contributions
10.4 Practical implications
10.5 Limitations
10.6 Recommendations for future works

10. Conclusion

This thesis has investigated the pathways toward circularity within the print and sign industry, specifically focusing on the recovery and recycling of PVC banners. The literature research highlights that while the material is currently a monstrous hybrid of fused PVC and PET that is 97% likely to be incinerated, the adoption of recycled composites like Sign Again offers a viable pathway to close the loop. By exploring the current system's limitations and opportunities through qualitative research and material testing, this study has provided a holistic view of the value chain. The research concludes that while technical challenges exist, the primary obstacles to a circular system are rooted in information gaps and systemic fragmentation.

10.1 Discussion

This research demonstrates that the transition to circularity for PVC/PET banners is not primarily a technical challenge, but an economic and systemic one. While the fused nature of these monstrous hybrids presents a thermal mismatch for traditional recycling, the primary barrier is the 'systemic ceiling' of rigid procurement and the 'economic floor' of artificially low virgin material costs.

This chapter reflects on these research findings, the developed concepts and their position within the broader context of the print and sign industry. While the developed tools provide a starting point, a critical analysis suggests that the industry's challenges extend far beyond the technicalities of recycling.

10.1.1 Positioning the concepts

The Sign Again guidebook and texture board are strategically positioned in phase 1 (short-term, 2025–2030) of the proposed roadmap. These tools are designed to bridge the information gap, found during the expert interviews, and the tactile gap identified during the validation phase. By providing transparent, comparable and actionable data, the guidebook aims to address the Economic and Systemic barriers of marketing challenges and low awareness cited by the majority of experts interviewed.

In this phase, the tools act as boundary objects facilitating knowledge flows for designers, printers and potentially also for end users. However, while these tools aim to lower the threshold for adoption, they are merely interventions targeted at the waste created now. They address the symptoms of a lack of knowledge but cannot, on their own, fix a market that remains fundamentally designed for linear consumption.

10.1.2 Sign Again - not the final destination

A core tension in this research is whether Sign Again inadvertently hinders actual sustainable change, meaning fixing the inherently unsustainable use of the material PVC. Literature identifies PVC banners as a monstrous hybrid, fused materials that are technically incompatible for high quality recycling. Liu et al. (2022) confirm that the strong PET-PVC bond makes separation unviable, leaving incineration or landfilling as the default (97%).

The current solution is incomplete. Sign Again is a pragmatic necessity, a bridge to capture the large volume of waste existing today. However, we must be careful not to let 'recyclability' become an excuse to continue producing hybrid waste. Shifting the current system to repurposing the material is a positive first step, but as defined by the Ellen MacArthur Foundation (2021), a true circular economy must eventually design out waste entirely, refusing the material all together. Sign Again keeps the material in the loop for up to seven cycles, but it still operates within a finite materials loop that eventually degrades.

10.1.3 Policy, behaviour and responsibility

Beyond the material science, this research has highlighted that the print and sign industry suffers from a profound lack of accountability. During the expert interviews, it became clear that responsibility is being passed around while no one takes ownership.

Behavioural barriers
The industry is addicted to the low cost and convenience of virgin PVC. There is a bounded rationality in procurement where the immediate bottom line outweighs long-term environmental costs.

Policy gaps
Currently, there is a lack of EPR for temporary signage. Without policies that penalise incineration or mandate a minimum percentage of recycled content, circular materials like Sign Again will always struggle to compete with the 'floor' of artificially cheap virgin plastics.

Systemic failure
The industry focuses too heavily on the recycling because it requires the least change in behaviour. True circularity requires moving up the R-Ladder toward refuse and rethink, concepts the industry is currently hesitant to embrace because they challenge the high-volume business model.

10.1.4 Strategic scaling

To move beyond small-scale pilots, approaching large-scale conventions or venues like RAI Amsterdam could be a great opportunity. As a consumer of temporary signage with an average functional lifespan of just 45 days, the RAI has the market power to demand change. By integrating the guidebook into their procurement contracts and adopting PSS, they can shift the responsibility back to the suppliers. This would force a move toward a model where the material is not sold and forgotten but managed as a resource.

10.2 Answering the research questions

To address the main research objective, which was to develop and test a theoretical framework that assists designers in establishing sustainable recovery practices for PVC/PET banner waste, the study answered two core sub questions:

Sub question 1
What system interventions could enable more sustainable practices for banners across the value chain?
The research identified that the primary barriers to circularity are not technical, but Economic and Systemic. The most critical interventions required are the establishment of formal take-back and return systems to capture material value and a shift toward PSS, such as leasing modular event flooring rather than selling single-use signs.

Sub question 2
What are the environmental and technical limitations and opportunities of PVC/PET banners throughout their lifecycle?
Technical testing revealed that Sign Again is a highly ductile and impact-absorbent material, making it ideal for compressive applications like road plates and event flooring. However, its heterogeneous density and low tensile strength mean it must not be used for high-tension structural loads. Environmentally, while it stabilises banner waste, its hybrid nature means mechanical recycling is a transitional solution until the industry can shift toward mono-materials.

Main research question
How can the Sign Again panel material be optimised in the market to move closer to a fully circular system for PVC/PET banner waste within the print and sign industry?
Sign Again can be optimised by bridging the information and value disconnect between stakeholders. Currently, the material is under utilised because companies and end-consumers lack clear data on its properties. This project addressed this optimisation through the creation of the Sign Again guidebook and a Strategic Roadmap, which together guide the industry from initial awareness to total systemic integration with upcoming EU legislation like EPR.

10.3 Literature contributions

This thesis contributes to the field of circular product design by shifting the focus from purely technical material recovery to the economic and systemic facilitators of the transition.

It provides a theoretical framework that maps the ‘ceilings’ and ‘floors’ of the print and sign industry, offering a new lens through which to analyse the failure of current circular business models in the face of low virgin material prices. The research developed and validated this theoretical framework through twelve expert interviews. The framework serves as an applied model that prioritises Economic and Systemic factors that define the solution space for circular materials. Secondly, is identifies various factors which has influence on the established domains. Honing in on any of these factors and consequently the domain had potential to produce sustainable recovery practices for PVC banner waste and great positive changes towards a circular economy for the print and sign industry.

10.4 Practical implications

The designed solutions aim to fill the knowledge gap found in the system by gathering fragmented knowledge into one place, allowing designers to justify the adoption of recycled alternatives through transparent storytelling. For the industry, this research provides immediate, tangible tools:

The Sign Again guidebook
A B2B procurement asset that translates complex material properties into comparable data, reducing the cognitive load for decision-makers.

The Sign Again texture board
A physical validation tool that reduces the tactile gap, allowing designers to trust the structural integrity and aesthetic potential of repurposed panels.

The strategic roadmap
A phased plan that allows companies like Horizonteer to transition from immediate waste capture (Phase 1) to long-term systemic change and policy compliance (Phase 3).

10.5 Limitations

While this study provides a robust framework for adoption, it is subject to several limitations:

Accessibility and usability:
The Sign Again playbook is a conceptual prototype and has not yet undergone formal UX testing or been optimised for individuals with visual impairments or colour blindness. Furthermore, the sample size during the all interviews, co-creations and validation sessions were limited to the European context and expert.

Data and testing constraints:
Material tests provided a initial look of properties but did not focus on long-term durability data, such as UV-induced degradation or mechanical fatigue over a 10-year lifespan. Secondly, due to the unavailability of a CNC machine, samples were prepared manually. This may have introduced slight geometric inconsistencies. Furthermore, technical material tests utilised small sample sizes (5–10 specimens), making the data indicative rather than statistically definitive. As a heterogeneous composite made of shredded fragments, Sign Again's mechanical properties are probabilistic. Outliers in the data are an inherent characteristic of the material's composition. The use of a rigid testing jig may not perfectly replicate the flexible, real world deformations of the material in situations.

Actual sustainability speculation:
The research scope omitted a precise life cycle analysis (LCA) to determine if Sign Again is more sustainable than simply incinerating banners after use. To find out if all the extra logistics, processing and production of Sign Again actually more valuable.

Roadmap ssumptions:
The 20-year Strategic Roadmap is inherently speculative, relying on the assumption that EU Green Deal legislation will be strictly enforced.

10.6 Recommendations for further work

To move the industry to true circularity, the following steps are recommended:

- Pilot with large scale venue:

Engage with organisations like RAI Amsterdam. As major consumers of temporary signage (with 45-day lifespans), they have the market power to mandate circular procurement through their contracts.

- Upscaling the take-back logistics:

Expanding the take-back model to determine the most cost-effective methods for local collection and shredding at scale.

- Pushing high potential products:

Developing a robust business case for specific high-potential products identified in this study, such as modular event flooring or road plates. Designers should focus on high potential products, such as parasol bases and traffic cones, here the material's weight is a functional asset.

- Consumer behavioural change:

Future work should explore how to change consumer habits, moving away from cheap and disposable mentalities. This includes standardising ‘circular storytelling’ labels to help end-users reflect on the sustainability of their purchasing behaviour.

- Implement PSS:

Shift from selling banners to selling visibility. By retaining ownership of the material, suppliers are incentivised to ensure its return and repurposing into Sign Again panels.

- Conducting a full Life Cycle Assessment (LCA):

To find out and potentially validate if Sign Again is in fact adding a positive change to the system, compared to incineration, a full LCA should be conducted.

- Move up the R-Ladder:

Use the roadmap to gradually phase out PVC/PET hybrids. Phase 3 should focus on the refusal, designing for mono-materials that allow for high-quality and true closed-loop recycling.

- Advocate for policy change:

The industry must push for EPR schemes and taxes on virgin plastics to create an even playing field where the true cost of incineration is reflected in the price of the material.

By aligning technical validation with behavioural storytelling, this thesis provides the industry with the tools to start the transition, but its ultimate success depends on a fundamental shift in responsibility across the entire value chain.

Chapter 11.

Personal reflection

11.1 Feasibility
11.2 Viability
11.3 Desirability
11.4 Personal note

11. Personal reflection

This chapter entails a final reflection on the results of the thesis, this will be done on the basis of its feasibility, viability and desirability. Lasty, a personal note from the author concerning the whole process of the project will conclude this paper.

11.1 Feasibility
The final outputs of this thesis; the strategic roadmap, the Sign Again guidebook, and the texture board, demonstrate high implementation feasibility. Unlike a purely technical invention that requires years of R&D, these solutions utilise existing repurposing technology (Sign Again) and focus on solving the information gap.

From a technical perspective, the guidebook and texture board are ready for immediate use as boundary objects in B2B sales and procurement. However, as noted in the limitations, the stochastic nature of the material means that while it is feasible to produce these panels, designing with them requires a specific set of guidelines. The roadmap's phased approach acknowledges that while phase 1 (awareness) is highly feasible today, phase 3 (policy and refusal) will require external systemic shifts that are currently beyond the control of a single designer or company.

11.2 Viability
The viability of this project rests on the industry's ability to bridge the gap between the low cost of virgin PVC and the operational costs of circular recovery. Currently, the 'economic floor' is kept artificially low by the lack of disposal taxes.

However, the Sign Again model becomes viable when the focus shifts from selling a product to managing a resource. By targeting large-scale venues like RAI Amsterdam, the project taps into a market where the volume of waste is high enough to make collection and repurposing economically interesting. The viability is further reinforced by upcoming EU regulations regarding material passports and EPR. By positioning these tools now, Horizonteer's clients are not just being sustainable they are future-proofing their business model against a shifting regulatory landscape.

11.3 Desirability
Throughout the validation phase, it became clear that there is a high level of desirability for circular alternatives, but uncertainty often gets in the way of this desire. Designers want to make sustainable choices, but they fear functional failure or potential greenwashing. Rightfully so.

The texture board directly addresses the tactile gap, fulfilling a sensory desire to trust the material's rigidity and finish. Meanwhile, the guidebook satisfies the professional desire for transparent, comparable data. By transforming banner waste into a high-quality aesthetic panel, the project moves the conversation from "what do we do with this trash?" to "how can we use this valuable resource?" This shift makes the circular transition not just a moral obligation, but an aspirational design choice.

11.4 Personal note
Looking back at large projects like these, it always surprises me how fast time flies and how much more you would have liked to still continue to work or iterate on. The project is never truly finished and this is difficult to accept. I can say with confidence that this was the hardest project to round off and move on from. Every part of the project could have used more work and more attention, but in the end the art of studying is knowing when something is good enough by balancing quality and time management.

Then, in terms of content, the most challenging part of this thesis was accepting that a "perfect" technical recycling solution does not yet exist for these materials. It was a pivotal moment for me as a designer to realise that my contribution wasn't just about creating a new material, but about creating the clarity and tools necessary for people to actually use what is already available. Navigating the complexities of toxic gas risks during testing and the frustrations of a price-driven market taught me that sustainable design is as much about psychology and policy as it is about physical products. As a designer we have the responsibility to make positive changes and I believe that sustainable ones are too often overlooked. I was happy to see how many people are actively working on making their or other companies better on this regard.

I am grateful for the collaboration with Horizonteer and giving me the opportunity to collaborate during my graduation thesis, which allowed me to ground my academic research in the sometimes shocking reality of the real world. I hope this work serves as a small but insightful project for the print and sign industry that has been operating very linearly for too long. Or that other industries who are similarly stuck in this linear pattern can get inspired to change.

I also want to thank my supervisors who were always open for a chat and feedback session throughout the whole project. Thank you Shahrokh and Puck for always having time for me.

Amber Markus
Delft, May 2026



Figure 95. *The author with her concepts*

Chapter 12.

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Chapter 13.

Appendices

A Approved project brief
B Literature review
- B.1 Production process PVC
- B.2 Production process PET

C Research methodology
- C.1 Interview protocol
- C.2 Informed consent form
- C.3 Approved HREC documents

D Results co-creation
- D.1 Co-creation setup

E Material testing
- E.1 Banner pull test setup
- E.2 Banner pull test graphs
- E.3 Bending test setup
- E.4 Bending test graphs
- E.5 Bending test similar materials
- E.6 Tensile strength test setup
- E.7 Tensile strength graphs
- E.8 Tensile strength similar materials
- E.9 Screw pull test graphs
- E.10 Shore hardness test similar materials
- E.11 Comparison with similar materials
- E.12 Comparison with similar industries

F Design development
- F.1 Ideation how to's
  Illustrator laser cut file

13. Appendices

A. Approved project brief

DESIGN FOR our future

TU Delft

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME
Complete all fields and indicate which master(s) you are in

Family name	Markus	IDE master(s)	IPD ✓ Dfl SPD
Initials	A.K.M.	2nd non-IDE master	
Given name	Amber	Individual programme *(date of approval)*	
Student number	4932471	Medisign	
		HPM	

SUPERVISORY TEAM
Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Shahrokh Nikou	dept./section	DOS/RMCR
mentor	Puck Bos	dept./section	SDE/DfS
2nd mentor	Rein Hintzen		
client:	Horizonteer		
city:	Utrecht	country:	the Netherlands
optional comments			

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.

! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.

! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

Name Shahrokh Nikou Date 12 Sep 2025 Signature

CHECK ON STUDY PROGRESS
To be filled in **by SSC E&SA** (Shared Service Centre, Education & Student Affairs), after approval of the project brief by the chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total ____ EC

Of which, taking conditional requirements into account, can be part of the exam programme ____ EC

★	**YES**	all 1st year master courses passed
	NO	missing 1st year courses

Comments:

Sign for approval (SSC E&SA)

Name [redacted] Date 19 Sep 2025 Signature

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	★	Supervisory Team approved
NO		Supervisory Team not approved

Comments:

Based on study progress, students is ...

★	**ALLOWED** to start the graduation project
	NOT allowed to start the graduation project

Comments:

Sign for approval (BoEx)

Name [redacted] Date 23 Sep 2025 Signature

DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

Name student Amber Markus **Student number** 4,932,471

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Circularity within the Print and Sign industry: the recycling and alternatives of PVC waste

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)

The print and sign industry relies heavily on rigid and flexible materials such as polyvinyl chloride (PVC). PVC is affordable, durable and delivers high printing quality. These benefits, however, come with severe environmental drawbacks, especially when the banners reach the end of their life cycle (Beren & Beren, 2025). PVC banner waste is made out of printed substrates and are coated with inks, adhesives, and layered composites, all of which complicate mechanical recycling processes. As a result, much of this material is landfilled or incinerated, creating an urgent sustainability challenge. (Leatherbarrow, 2023)
The question would be how a sustainable and circular future can be designed with banners? PVC-free alternatives are becoming more popular, yet they often contain poorly tested mixtures of materials that may be even harder to recycle, undermining their environmental claims.
Another question here is how can the demands of the customer be met with a material that is fundamentally sustainable? These customers are producers, printing companies, and end customers which operate within a fragmented system. Their interests range from cost control and product performance to regulatory compliance and meeting consumer expectations. Increasingly strict environmental regulations, combined with growing customer demand for sustainable solutions, are reshaping industry priorities.
The overarching research question would be: How can sustainable pathways be developed for PVC banners and their alternatives in the print and sign industry?
The sub questions are: What interventions could enable more sustainable pathways for banners across the value chain? What are the environmental and technical limitations of PVC banners throughout their life cycle?
These questions can be partly answered by using existing frameworks such as material driven design (MDD) and circular design principles like the butterfly diagram.

➔ *space available for images / figures on next page*

introduction (continued): space for images

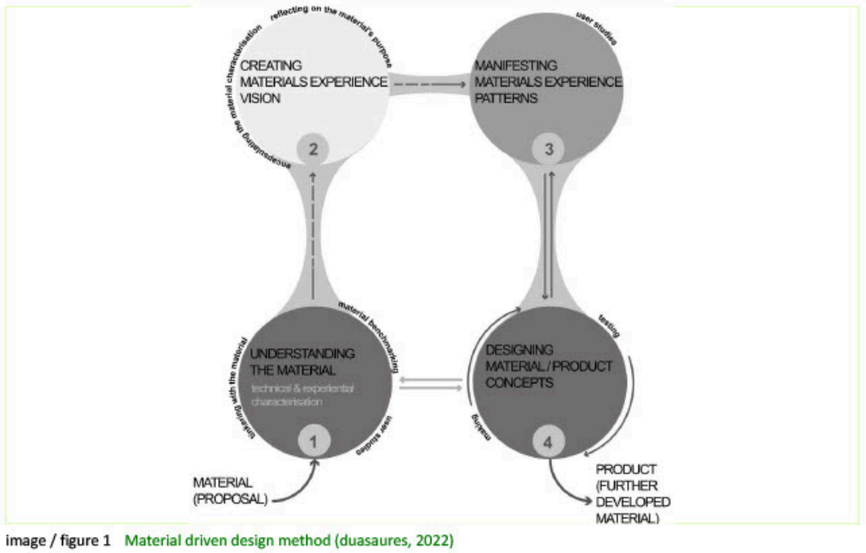


image / figure 1 Material driven design method (duasaures, 2022)

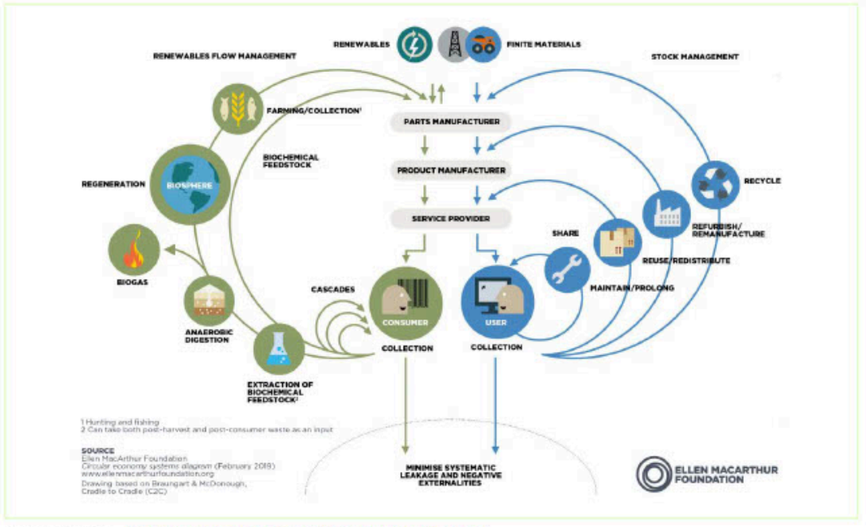


image / figure 2 Butterfly diagram (Ellen Macarthus Foundation, 2021)

DESIGN FOR our future

TU Delft

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 print & sign industry is facing a sustainability challenge. PVC substrates are widely used, but they are rarely recycled into high-quality, similar-use products. This is because they are often contaminated with inks, adhesives, and layered composites. (Bartolome, 2024) Current recycling methods struggle with several issues. First, there are material limitations, such as the loss of visual and functional quality. Second, there are economic barriers, since recycling or alternatives are more expensive than using virgin PVC. (Saatcioglu & Venkatraman, 2024) Third, there is stakeholder fragmentation, as producers, distributors, printers, and customers often have divergent incentives. At the same time, market and regulatory pressure is accelerating the demand for eco-conscious alternatives, many of which (e.g., so-called PVC-free substrates) are poorly tested, difficult to recycle, or environmentally ambiguous. (Horizonteer, 2025)
The aim of this project is to tackle the following aspects of the problem. By conducting a systematic investigation into the material and mainly organizational conditions that currently hinder circularity there is the opportunity to add value. Through system mapping, stakeholder analysis, and exploration of viable interventions, this research aims to identify leverage points where innovation could meaningfully improve sustainability outcomes. Based on these insights, potential directions for a conceptual product solution will be found that aligns with stakeholder interests while addressing core material and systemic challenges in a realistic and actionable way.

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 roadmap and prototype to improve the circularity of PVC banners for printing companies and distributors in the context of sustainable product development.

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)

Desk research and literature review will establish the current state in PVC recycling, alternative substrates, and circular design principles. Stakeholder mapping and semi-structured interviews with producers, distributors, and printers will provide insights into practical challenges, incentives, and system bottlenecks. To evaluate material and economic aspects, comparative case analysis and life cycle considerations can be applied.
On the design side, co-creation workshops with industry stakeholders will help generate feasible interventions and prioritize solutions. Scenario building can be used to structure the roadmap, outlining short-, medium-, and long-term pathways toward circularity. For the prototype, rapid prototyping and material testing will allow exploration of design-for-recycling strategies. Finally, expert validation through feedback sessions will ensure that both the roadmap and prototype align with real-world constraints and opportunities.

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting, mid-term evaluation meeting, green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	4 Sep 2025
Mid-term evaluation	30 Oct 2025
Green light meeting	8 Jan 2026
Graduation ceremony	6 Feb 2026

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

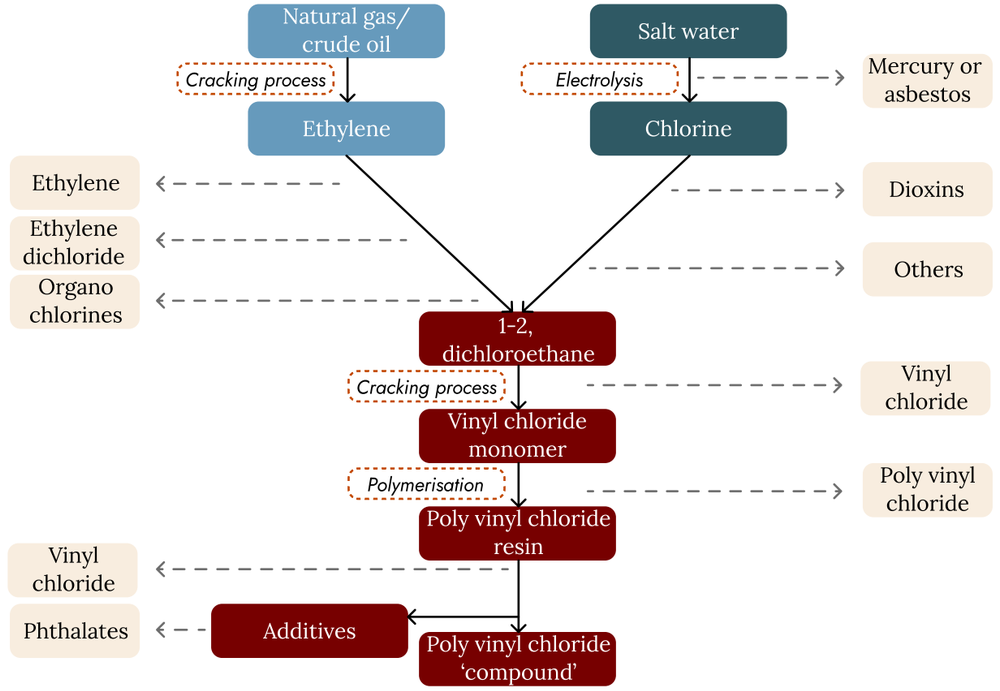
This project offers a last opportunity to work at a company, which I have not taken the chance to do yet within my studies. I'm excited to see a glimmer of how a design agency such as Horizonteer works and to ask about their experiences with real world clients and their problems to solve.

I am also looking forward to combining all the aspects I enjoy most of Industrial Design. This is part system engineering and also part product designing. During my minor I had a project combining these two, and this was one of my favourite projects till date. This is why I wanted to shape my graduation thesis similar to that project and see what I would do different now, 3 years later.

This project offers the chance to deepen expertise in circular design and sustainable materials. This aligns with a personal drive to create design outcomes that are environmentally impactful and economically viable, bridging the gap between research and practice.

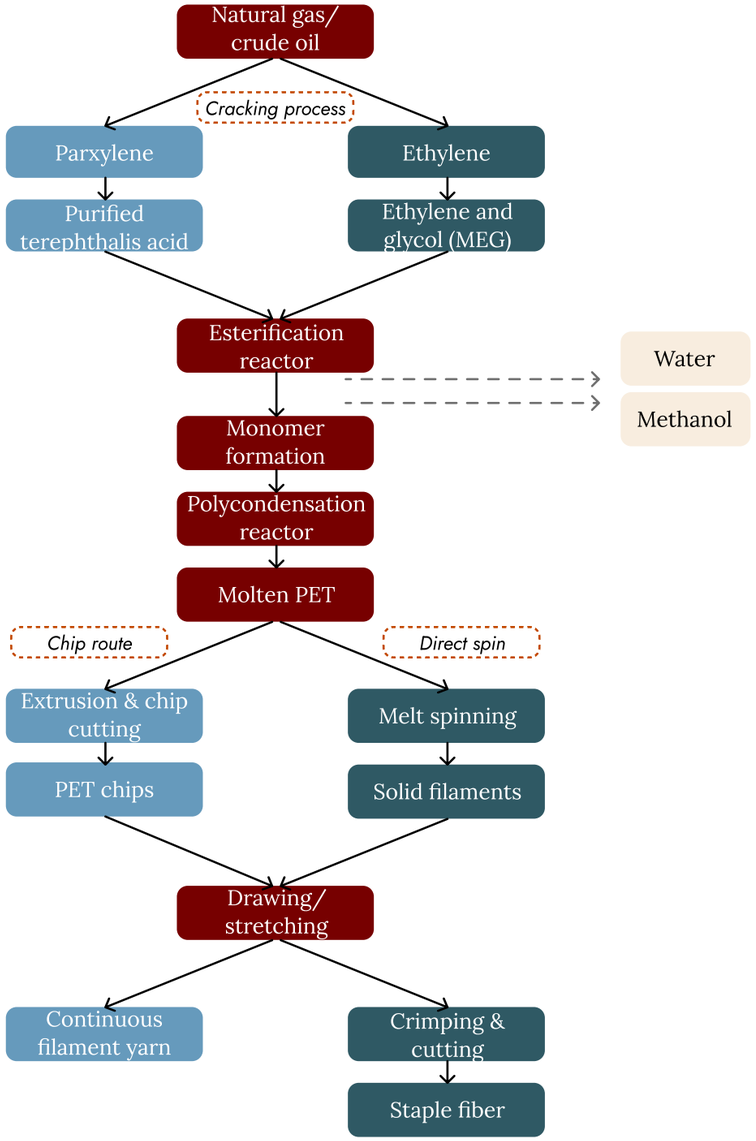
Lastly, I have a personal goal to effectively communicate with the reader of my report and visuals. I want to do this by challenging myself to create most of the icons, visuals and communication tools myself.

B.1 Production process of PVC (Yadav et al., 2018)



LITERATURE REVIEW

B.2 Production process of PET (Textile Vlog, 2021)



RESEARCH METHODOLOGY

C.1 Interview protocol

Give an introduction of the project and what their help would mean for the progress. Go through the consent form and explain that they can stop whenever they want. Ask to record the conversation and start the interview.

1. Background and role
   - Can you describe your role in the recycling with PVC banners?
   - How has demand for recycled or sustainable materials changed in recent years?

2. Production
   - What types of PVC (or PVC-free) materials do you typically work with?
   - How many (KG) banners are made per year?

3. Recycling
   - What are the main challenges in recycling printed PVC banners?
   - Are there any technical solutions or treatments that improve recyclability or separation?
   - From your perspective, what limits the reuse or upcycling of PVC banner material?

4. Economic and Market Factors
   - How do recycling costs compare to the production of virgin PVC or alternatives?
   - What economic or logistical barriers prevent large-scale recycling?
   - Do you see a market demand for recycled PVC materials? If not, what could stimulate it?

5. Sustainability and Alternatives
   - What is your opinion on “PVC-free” banner materials currently on the market?
   - What would make a banner material truly sustainable from your point of view?
   - How many (KG) banners do not immediately end up in landfills per year?
   - Is it promoted to use banners for more than one occasion?

6. Systemic and Collaboration Aspects
   - How well do manufacturers, printers, and recyclers currently collaborate?
   - What kind of coordination or partnerships would help improve collection and recycling rates?
   - Who are the important stakeholders?
   - Who in the value chain has the most influence to change this system?

7. Innovations
   - What kind of innovation or infrastructure investment would make PVC banner recycling more viable?
   - In your view, what should be the priority for achieving a more circular system?

8. Closing
   - If you could change one thing about how banners are made or recycled, what would it be?
   - Is there anything you would like to add which we haven’t discussed?

Thank the interviewee for their time and ask if there are any more questions.

Date: [ ].10.2025
Study Title: Circularity within the Print and Sign industry: the recycling and alternatives of PVC waste
Researcher: Amber Markus
Contact: A.K.Markus@student.tudelft.nl

Dear [Name],

Thank you very much for considering this invitation to participate in my thesis research. I am conducting a study on Circularity within the Print and Sign industry as part of the graduation project at Delft University of Technology. I would be grateful for your participation in a 30-60minute interview (online/in person) at a time convenient to you.

Participation is entirely voluntary. You may decline to answer any question and may stop the interview at any time without providing a reason. With your permission, the interview will be audio-recorded solely to ensure accuracy of the transcript.

All your responses, your identity, and any identifying details will be anonymised in notes, transcripts, and any outputs. Your data will be kept confidential and will not be shared with anyone beyond this thesis project (i.e. only the researcher and the academic supervisor). Data will be stored securely and used only for academic purposes related to this thesis.

If you are willing to take part, please review the information below and sign the consent section at the end of this document (or reply by email indicating your consent to each item).

Kind regards,
Amber Markus

Participant Information

What is this study about?

This interview explores how sustainable recovery practices van be developed for PVC banner waste within the print and sign industry and who is involved in its value chain. The session will last approximately 30-60 minutes and will be held [online/in person].

Voluntary participation and right to withdraw

Participation is voluntary, and you may refuse to answer any question.
You may withdraw at any time during the interview without giving a reason. If you withdraw, your data will be deleted.

Confidentiality, anonymisation, and data use

Your identity and any identifying details will be anonymised in notes, transcripts, and any publications/presentations arising from this research.
Your data will be kept confidential and will not be shared with anyone beyond this thesis project (limited to the researcher and the academic supervisor).

Data will be stored securely on approved storage with restricted access.
Data will be used only for academic purposes related to this thesis (and examination) and not for commercial use.

Recording and transcription

With your permission, the interview will be audio-recorded to ensure accurate transcription. Transcripts will be anonymised and checked for accuracy. Audio files will be deleted after transcription and verification

Risks and benefits

There are no anticipated risks beyond a normal professional conversation. You may skip any question.
There is no direct compensation; however, your insights contribute to knowledge and practice.

Consent

Please indicate your agreement by initialing or ticking each item and signing below.

[] I have read and understood the information above and have had the opportunity to ask questions.
[] I understand participation is voluntary and that I may withdraw during the interview and up to a week after the interview without giving a reason.
[] I consent to the interview being audio-recorded for transcription accuracy.
[] I understand that my identity and any identifying details will be anonymised, my data will be kept confidential, and it will not be shared beyond this thesis project.
[] I consent to the use of my anonymised responses for the thesis and related academic assessment.

Participant name: _____
Signature: _____
Date: _____

Delft University of Technology
HUMAN RESEARCH ETHICS
CHECKLIST FOR HUMAN RESEARCH
(Version January 2022)

IMPORTANT NOTES ON PREPARING THIS CHECKLIST

1. An HREC application should be submitted for every research study that involves human participants (as Research Subjects) carried out by TU Delft researchers
2. Your HREC application should be submitted and approved **before** potential participants are approached to take part in your study
3. All submissions from Master's Students for their research thesis need approval from the relevant Responsible Researcher
4. The Responsible Researcher must indicate their approval of the completeness and quality of the submission by signing and dating this form OR by providing approval to the corresponding researcher via email (included as a PDF with the full HREC submission)
5. There are various aspects of human research compliance which fall outside of the remit of the HREC, but which must be in place to obtain HREC approval. These often require input from internal or external experts such as Faculty Data Stewards, Faculty HSE advisors, the TU Delft Privacy Team or external Medical research partners.
6. You can find detailed guidance on completing your HREC application here
7. Please note that incomplete submissions (whether in terms of documentation or the information provided therein) will be returned for completion **prior to any assessment**
8. If you have any feedback on any aspect of the HREC approval tools and/or process you can leave your comments here

I. Applicant Information

PROJECT TITLE:	**Circularity within the Print and Sign industry: the recycling and alternatives of PVC waste**
Research period: *Over what period of time will this specific part of the research take place*	**20 weeks (5th September 2025 – 6th Febuary 2026)**
Faculty:	**Industrial Design Engineering**
Department:	**Integrated Product Design**
Type of the research project: *(Bachelor's, Master's, DreamTeam, PhD, PostDoc, Senior Researcher, Organisational etc.)*	**Master's Thesis**
Funder of research: *(EU, NWO, TUD, other – in which case please elaborate)*	**NA**
Name of Corresponding Researcher: *(If different from the Responsible Researcher)*	**Amber Markus**
E-mail Corresponding Researcher: *(If different from the Responsible Researcher)*	**a.k.markus@student.tudelft.nl**
Position of Corresponding Researcher: *(Masters, DreamTeam, PhD, PostDoc, Assistant/ Associate/ Full Professor)*	**Masters Student**
Name of Responsible Researcher: ***Note:*** *all student work must have a named Responsible Researcher to approve, sign and submit this application*	**Dr. Shahrokh Nikou**
E-mail of Responsible Researcher: *Please ensure that an institutional email address (**no Gmail, Yahoo, etc.**) is used for all project documentation/ communications including Informed Consent materials*	**S.N.Nikou@tudelft.nl**
Position of Responsible Researcher : *(PhD, PostDoc, Associate/ Assistant/ Full Professor)*	**Assistant Professor**

II. Research Overview

NOTE: *You can find more guidance on completing this checklist here*

a) Please summarise your research very briefly (100-200 words)
What are you looking into, who is involved, how many participants there will be, how they will be recruited and what are they expected to do?

Add your text here – (please avoid jargon and abbrevations)

This project investigates how sustainable recovery practices can be developed for PVC banner waste within the print and sign industry. Over the course of 100 working days, the research combines system mapping, stakeholder analysis, and material evaluation to identify barriers and opportunities for circularity. The study addresses material limitations, economic feasibility, stakeholder complexity, and customer demands, aiming to reconcile environmental responsibility with industry requirements.

The outcome is both a roadmap outlining potential transition pathways and a prototype that demonstrates one feasible intervention. Together, they provide insights and practical directions for stakeholders in the print and sign industry seeking sustainabable solutions.

Participants for the interiews will be found through the collaborating company, Horizonteer or through my own desk research. The aim is to find 10-15 participants from different parts of the value chain, to gain a holistic view of the system. They will be interviewed through

semi-structured interviews. A survey may be conducted later in the project to get feedback on the proposed solution space.

b) **If your application is an additional project** related to an existing approved HREC submission, please provide a brief explanation including the existing relevant HREC submission number/s.

Add your text here – (please avoid jargon and abbrevations)

c) **If your application is a simple extension of, or amendment to,** an existing approved HREC submission, you can simply submit an HREC Amendment Form as a submission through LabServant.

III. Risk Assessment and Mitigation Plan

NOTE: *You can find more guidance on completing this checklist here*

Please complete the following table in full for all points to which your answer is "yes". Bear in mind that the vast majority of projects involving human participants as Research Subjects also involve the collection of **Personally Identifiable Information (PII)** and/or **Personally Identifiable Research Data (PIRD)** which may pose potential risks to participants as detailed in Section G: Data Processing and Privacy below.

To ensure alignment between your risk assessment, data management and what you agree with your Research Subjects you can use the last two columns in the table below to refer to specific points in your Data Management Plan (DMP) and Informed Consent Form (ICF) **– but this is not compulsory**.

It's worth noting that **you're much more likely to need to resubmit your application if you neglect to identify potential risks**, than if you identify a potential risk and demonstrate how you will mitigate it. If necessary, the HREC will always work with you and colleagues in the Privacy Team and Data Management Services to see how, if at all possible, your research can be conducted.

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
A: Partners and collaboration						
1. Will the research be carried out in collaboration with additional organisational partners such as: • One or more collaborating research and/or commercial organisations • Either a research, or a work experience internship provider[1] [1] *If yes, please include the graduation agreement in this application*	**Yes**		**Employees may feel obligated to participate in interviews, workshops, or surveys because their employer is involved, even if they don't want to. Companies often deal with sensitive information (business models, financials, strategies). Sharing or publishing this without safeguards could harm the company or individuals. The company may want to influence the research outcome in its favor.**	**Voluntary participation** and informed consent will be ensured. Anonymity of data weill be guaranteed and data will be handled securely. Boundaries with the company are clarified and a contract has been signed.		
2. Is this research dependent on a Data Transfer or Processing Agreement with a collaborating partner or third party supplier? *If yes please provide a copy of the signed DTA/DPA*		**No**				
3. Has this research been approved by another (external) research ethics committee (e.g.: HREC and/or MREC/METC)? *If yes, please provide a copy of the approval (if possible) and summarise any key points in your Risk Management section below*		**No**				

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
B: Location						
4. Will the research take place in a country or countries, other than the Netherlands, within the EU?		**No**				
5. Will the research take place in a country or countries outside the EU?		**No**				
6. Will the research take place in a place/region or of higher risk – including known dangerous locations (in any country) or locations with non-democratic regimes?		**No**				
C: Participants						
7. Will the study involve participants who **may** be vulnerable and possibly (legally) unable to give informed consent? (e.g., children below the legal age for giving consent, people with learning difficulties, people living in care or nursing homes,).		**No**				
8. Will the study involve participants who **may** be vulnerable under specific circumstances and in specific contexts, such as victims and witnesses of violence, including domestic violence; sex workers; members of minority groups, refugees, irregular migrants or dissidents?		**No**				
9. Are the participants, outside the context of the research, in a dependent or subordinate position to the investigator (such as own children, own students or employees of either TU Delft and/or a collaborating partner organisation)? *It is essential that you safeguard against possible adverse consequences of this situation (such as allowing a student's failure to participate to your satisfaction to affect your evaluation of their coursework).*		**No**				
10. Is there a high possibility of re-identification for your participants? (e.g., do they have a very specialist job of which there are only a small number in a given country, are they members of a small community, or employees from a partner company collaborating in the research? Or are they one of only a handful of (expert) participants in the study?		**No**				
D: Recruiting Participants						
11. Will your participants be recruited through your own, professional, channels such as conference attendance lists, or through specific network/s such as self-help groups		**No**				
12. Will the participants be recruited or accessed in the longer term by a (legal or customary) gatekeeper? (e.g., an adult professional working with children; a		**No**				

RESEARCH METHODOLOGY
C.3 Approved HREC documents

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
community leader or family member who has this customary role – within or outside the EU; the data producer of a long-term cohort study)						
13. Will you be recruiting your participants through a crowd-sourcing service and/or involve a third party data-gathering service, such as a survey platform?		**No**				
14. Will you be offering any financial, or other, remuneration to participants, and might this induce or bias participation?		**No**				
E: Subject Matter *Research related to medical questions/health may require special attention. See also the website of the CCMO before contacting the HREC.*						
15. Will your research involve any of the following: • Medical research and/or clinical trials • Invasive sampling and/or medical imaging • Medical and *In Vitro Diagnostic Medical* Devices Research		**No**				
16. Will drugs, placebos, or other substances (e.g., drinks, foods, food or drink constituents, dietary supplements) be administered to the study participants? *If yes see here to determine whether medical ethical approval is required*		**No**				
17. Will blood or tissue samples be obtained from participants? *If yes see here to determine whether medical ethical approval is required*		**No**				
18. Does the study risk causing psychological stress or anxiety beyond that normally encountered by the participants in their life outside research?		**No**				
19. Will the study involve discussion of personal sensitive data which could put participants at increased legal, financial, reputational, security or other risk? (e.g., financial data, location data, data relating to children or other vulnerable groups) *Definitions of sensitive personal data, and special cases are provided on the TUD Privacy Team website.*		**No**				
20. Will the study involve disclosing commercially or professionally sensitive, or confidential information? (e.g., relating to decision-making processes or business strategies which might, for example, be of interest to competitors)		**No**				
21. Has your study been identified by the TU Delft Privacy Team as requiring a Data Processing Impact Assessment (DPIA)? *If yes please attach the advice/ approval from the Privacy Team to this application*		**No**				
22. Does your research investigate causes or areas of conflict?		**No**				

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
If yes please confirm that your fieldwork has been discussed with the appropriate safety/security advisors and approved by your Department/Faculty.						
23. Does your research involve observing illegal activities or data processed or provided by authorities responsible for preventing, investigating, detecting or prosecuting criminal offences *If so please confirm that your work has been discussed with the appropriate legal advisors and approved by your Department/Faculty.*		**No**				
F: Research Methods						
24. Will it be necessary for participants to take part in the study without their knowledge and consent at the time? (e.g., covert observation of people in non-public places).		**No**				
25. Will the study involve actively deceiving the participants? (For example, will participants be deliberately falsely informed, will information be withheld from them or will they be misled in such a way that they are likely to object or show unease when debriefed about the study).		**No**				
26. Is pain or more than mild discomfort likely to result from the study? And/or could your research activity cause an accident involving (non-) participants?		**No**				
27. Will the experiment involve the use of devices that are not 'CE' certified? *Only, if 'yes': continue with the following questions:*		**No**				
• Was the device built in-house?						
• Was it inspected by a safety expert at TU Delft? *If yes, please provide a signed device report*						
• If it was not built in-house and not CE-certified, was it inspected by some other, qualified authority in safety and approved? *If yes, please provide records of the inspection*						
28. Will your research involve face-to-face encounters with your participants and if so how will you assess and address Covid considerations?	**Yes**		Risk of contracting or spreading Covid-19 (or other airborne/surface spreading illnesses).	Where meetings happen in person rather than online, good hygiene and social distancing practices will be communicated with and maintained by the research team. In case of a resurgence of high Covid-19 numbers, depending on government and TU Delft's guidelines, researchers will adhere to the given instructions like 1) wear an effective mask, or 2) move interviews online. Researchers will also self assess their		

			If YES please complete the Risk Assessment and Mitigation Plan columns below.		*Please provide the relevant reference #*	
ISSUE	**Yes**	**No**	**RISK ASSESSMENT – what risks could arise?** *Please ensure that you list ALL of the actual risks that could potentially arise – do not simply state whether you consider any such risks are important!*	**MITIGATION PLAN – what mitigating steps will you take?** *Please ensure that you summarise what actual mitigation measures you will take for each potential risk identified – do not simply state that you will e.g. comply with regulations.*	**DMP**	**ICF**
				health prior to meeting with participants to ensure they are not exhibiting symptoms of Covid-19.		
29. Will your research involve **either:** a) "big data", combined datasets, new data-gathering or new data-merging techniques which might lead to re-identification of your participants **and/or** b) artificial intelligence or algorithm training where, for example biased datasets could lead to biased outcomes?		**No**				
G: Data Processing and Privacy						
30. Will the research involve collecting, processing and/or storing any directly identifiable PII (Personally Identifiable Information) including name or email address that will be used for administrative purposes only? (eg: obtaining Informed Consent or disbursing remuneration)	**Yes**		Risk of sharing personal information outside of administrative research activities. This could lead to identification of interview participants impacting their privacy	In case of a quantitative analysis during the validation phase of the study, reputed tools like Qualtrics and Microsoft forms shall be used with the TU Delft student account. This ensures that the data is protected as per TU Delft's quality requirements. Apart from that, no personal data apart from the name, email Ids and organizational role would be collected, which would be handled with outmost caution using only TU Delft's Onedrive tool and shall be deleted within 3 months of end of project.	**DMP**	
31. Will the research involve collecting, processing and/or storing any directly or indirectly identifiable PIRD (Personally Identifiable Research Data) including videos, pictures, IP address, gender, age etc and **what other Personal Research Data** (including personal or professional views) will you be collecting?		**No**				
32. Will this research involve collecting data from the internet, social media and/or publicly available datasets which have been originally contributed by human participants		No				
33. Will your research findings be published in one or more forms in the public domain, as e.g., Masters thesis, journal publication, conference presentation or wider public dissemination?	**Yes**		The research will be published as a "Master's Thesis"	Personal Data from the Participant shall not be published with the thesis. Only essential insights shall be published in an anonymised manner so that it is impossible to relate the quotes/ insights back to the participants.	DMP	
34. Will your research data be archived for re-use and/or teaching in an open, private or semi-open archive?		**No**				

H: More on Informed Consent and Data Management

NOTE: *You can find guidance and templates for preparing your Informed Consent materials) here*

Your research involves human participants as Research Subjects if you are recruiting them or actively involving or influencing, manipulating or directing them in any way in your research activities. This means you must seek informed consent and agree/ implement appropriate safeguards regardless of whether you are collecting any PIRD.

Where you are also collecting PIRD, and using Informed Consent as the legal basis for your research, you need to also make sure that your IC materials are clear on any related risks and the mitigating measures you will take – including through responsible data management.

Got a comment on this checklist or the HREC process? You can leave your comments here

IV. Signature/s

Please note that by signing this checklist list as the sole, or Responsible, researcher you are providing approval of the completeness and quality of the submission, as well as confirming alignment between GDPR, Data Management and Informed Consent requirements.

Name of Corresponding Researcher (if different from the Responsible Researcher) (print)

Signature of Corresponding Researcher:

Date: 29.09.25

Name of Responsible Researcher (print)
Shahrokh Nikou

Signature (or upload consent by mail) Responsible Researcher:

Date: 30.09.2025

V. Completing your HREC application

Please use the following list to check that you have provided all relevant documentation

Required:

- **Always:** This completed HREC checklist
- **Always:** A data management plan (reviewed, where necessary, by a data-steward)
- **Usually:** A complete Informed Consent form (including Participant Information) and/or Opening Statement (for online consent)

Please also attach any of the following, if relevant to your research:

Document or approval	**Contact/s**
Full Research Ethics Application	After the assessment of your initial application **HREC will let you know if and when you need to submit additional information**
Signed, valid Device Report	Your Faculty HSE advisor
Ethics approval from an external Medical Committee	TU Delft Policy Advisor, Medical (Devices) Research
Ethics approval from an external Research Ethics Committee	Please append, if possible, with your submission
Approved Data Transfer or Data Processing Agreement	Your Faculty Data Steward and/or TU Delft Privacy Team
Approved Graduation Agreement	Your Master's thesis supervisor
Data Processing Impact Assessment (DPIA)	TU Delft Privacy Team
Other specific requirement	Please reference/explain in your checklist and append with your submission

Plan Overview

A Data Management Plan created using DMPonline

Title: Circularity within the Print and Sign industry: the recycling and alternatives of PVC waste

Creator: Amber Markus

Affiliation: Delft University of Technology

Template: TU Delft Data Management Plan template (2025)

Project abstract:

This project investigates how sustainable recovery practices can be developed for PVC banner waste within the print and sign industry. Over the course of 100 working days, the research combines system mapping, stakeholder analysis, and material evaluation to identify barriers and opportunities for circularity. The study addresses material limitations, economic feasibility, stakeholder complexity, and customer demands, aiming to reconcile environmental responsibility with industry requirements.

The outcome is both a roadmap outlining potential transition pathways and a prototype that demonstrates one feasible intervention. Together, they provide insights and practical directions for stakeholders in the print and sign industry seeking sustainabable solutions.

ID: 186629

Start date: 05-09-2025

End date: 06-02-2026

Last modified: 29-09-2025

Circularity within the Print and Sign industry: the recycling and alternatives of PVC waste

0. Administrative questions

None

- Yes, leading the collaboration – please provide details of the type of collaboration and the involved parties below

The project is commissioned by Horizonteer, a design agency in Utrecht.

I. Data/code description and collection or re-use

Type of data/code	**File format(s)**	**How will data/code be collected/generated?** *For re-used data/code: what are the sources and terms of use?*	**Purpose of processing**	**Storage location**	**Who will have access to the data/code?**
Personally Identifiable Information for informed consent forms	.pdf	Informed consent forms signed digitally	To obtain and document informed consent.	Project Data Storage	The TUD project team (Shahrokh Nikou, chair and mentor: Puck Bos and Rein Hintzen)
Anonymized data (Age, education, gender	.xlsx .csv	An online survey using Microsoft Forms/Qualtrics; responses collected anonymously.	To obtain opinions of potential final users concerning design results	Project Data Storage	As above
Audio recording + transcript	.mpeg .docx	Semi-structured interviews	To understand the point of view of experts concerning PVC banner recycling/reuse	Project Data Storage	As above

II. Storage and backup during the research process

- < 250 GB

- Project Data Storage (U:) drive at TU Delft

III. Data/code documentation

- Data – Methodology of data collection

IV. Legal and ethical requirements, code of conducts

- Yes – please provide details in the additional information box below

Will be handed in together with HREC.

- Yes

- No, I will not work with any other types of confidential or classified data/code

The intellectual property rights are framed by a graduation agreement between Delft University of Technology, myself and Horizonteer.

- Proof of consent (such as signed consent materials which contain name and signature)
- Audio recordings
- Video materials
- Photographs
- Job title and/or employer
- Telephone number, email addresses and/or other addresses as contact details for administrative purposes
- Date of birth and/or age
- Gender
- Names as contact details for administrative purposes

Experts on in the domain of PVC banner recycling and companies working with banners to upcycle them. All in the Netherlands.

- No

- Informed consent

The researcher will inform the potential participants about the goals and procedures of the research project. The researcher will also inform them about the personal data that are being processed and for what purpose. This information will be provided to the potential participants as follows: a digital copy of the information will be emailed to participants before the interview. All participants will be asked for their consent for taking part in the study and for data processing by signing a digital informed consent form before the start of the interview.

The proof of consent (digital copy of signed document) will be preserved on the TU Delft Project Data Storage (U:) drive.

- None of the above apply

- Anonymised or aggregated data will be shared with others

- Personal data will be deleted at the end of the research project

- In the informed consent form: participants are informed that their personal data will be anonymised and that the anonymised dataset is shared publicly

V. Data sharing and long term preservation

- All other non-personal data/code produced in the project

- I am a Bachelor's/Master's student at TU Delft and I will share the data/code in the body and/or appendices of my thesis/report in the TU Delft Repository

- < 100 GB

- At the end of the research project

- CC BY

VI. Data management responsibilities and resources

My supervisor: Dr. Shahrokh Nikou, Assistant Professor from DOS with email address S.N.Nikou@tudelft.nl

No extra cost or time will be dedicated to the data management of this research other than space available in OneDrive and Repository.

- Faculty of Industrial Design Engineering (IDE)

RESEARCH METHODOLOGY
C.3 Approved HREC documents

Date 11-Dec-2025
Correspondence hrec@tudelft.nl

TU Delft Delft University of Technology

Human Research Ethics Committee TU Delft
(http://hrec.tudelft.nl)

Visiting address
Jaffalaan 5 (building 31)
2628 BX Delft

Postal address
P.O. Box 5015 2600 GA Delft
The Netherlands

Ethics Approval Application: Circularity within the Print and Sign industry: The recycling and alternatives of PVC waste
Applicant: Markus, Amber

Dear Amber Markus,

It is a pleasure to inform you that your application mentioned above has been approved.

Thanks very much for your submission to the HREC which has been approved.

In addition to any specific conditions or notes, the HREC provides the following standard advice to all applicants:
• In light of recent tax changes, we advise that you confirm any proposed remuneration of research subjects with your faculty contract manager before going ahead.
• Please make sure when you carry out your research that you confirm contemporary covid protocols with your faculty HSE advisor, and that ongoing covid risks and precautions are flagged in the informed consent - with particular attention to this where there are physically vulnerable (eg: elderly or with underlying conditions) participants involved.
• Our default advice is not to publish transcripts or transcript summaries, but to retain these privately for specific purposes/checking; and if they are to be made public then only if fully anonymised and the transcript/summary itself approved by participants for specific purpose.
• Where there are collaborating (including funding) partners, appropriate formal agreements including clarity on responsibilities, including data ownership, responsibilities and access, should be in place and that relevant aspects of such agreements (such as access to raw or other data) are clear in the Informed Consent.

Good luck with your research!

Sincerely,

Dr. C. Shelley-Egan
Chair HREC
Faculty of Technology, Policy and Management

RESULTS CO-CREATION

D.1 Co-creation setup

5-10 min:
Explanation of the purpose of the co creation session.
It would be best to write down the thoughts you have and share the most important ones with the group to have a short discussion. Other ideas, feedback or thoughts would be great to share after the session via email.

10 min:
Validation of the trends found and value driver:
These trends

Trends
Trend 1: Expansion of Circular Economy Legislation
Trend 2: Restrictions on PVC & hazardous additives
Trend 3: Rise of Sustainable Procurement
Trend 4: Short-lived products shifting toward reusable systems
Trend 5: Advances in mechanical recycling & composite panel engineering
Trend 6: Digital fabrication adoption
Trend 7: Rising disposal costs & incineration taxes
Trend 8: Emerging circular business models
Trend 9: Social enterprises integrated in circular systems
Trend 10: Demand for low-carbon, durable materials

Key value drivers
Compliance capability of businesses with evolving EU legislation
Creating awareness for business and consumers relating to their usage habits
Being able to transformed PVC banner waste into valuable material
Create a new circular business model which enables recycling companies to grow
Creating cross-sector collaboration culture to enable closed loops

Are there any drivers missing to complete the list better

20 min:
Discussion Pillar 1
Discuss steps needed to achieve pillar vision
Show concepts.

10 min:
Discussion Pillar 2
Discuss steps needed to achieve pillar vision

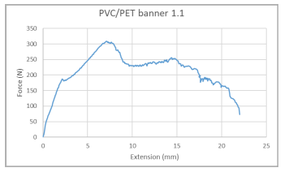
10 min:
Discussion Pillar 3
Discuss steps needed to achieve pillar vision

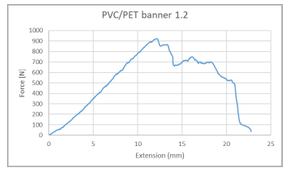
MATERIAL TESTING

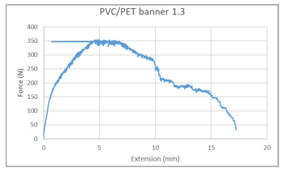
E.1 Banner pull test setup

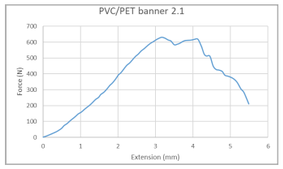
The software was setup to measure with the following:
Sensor: 500 kg
Test type: Tensile
Subtest: fail
Speed (mm/min): 10
X-axis: force
Y-axis: displacement

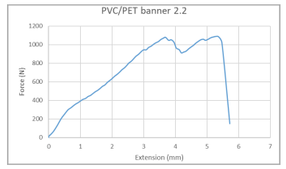
E.2 Banner pull test graphs

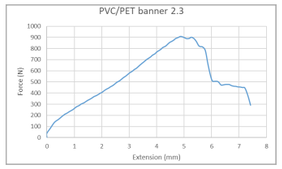


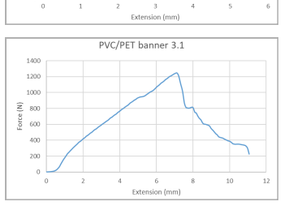


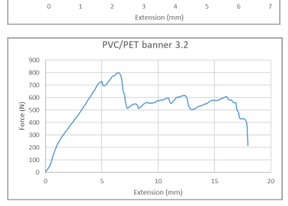


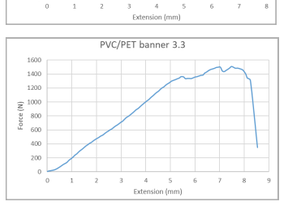


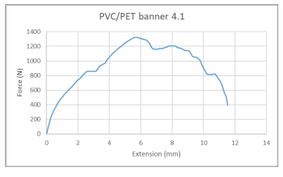


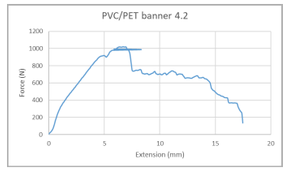


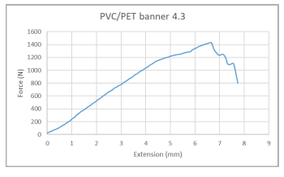


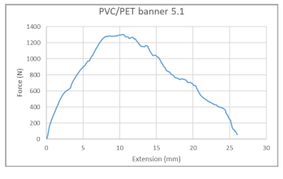


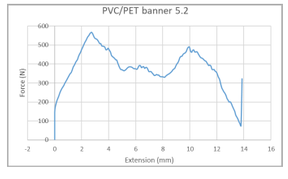


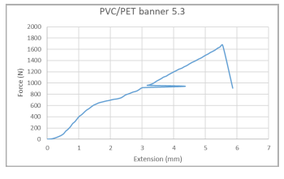


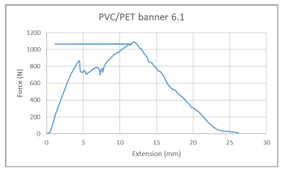


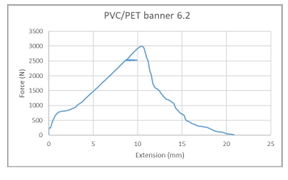


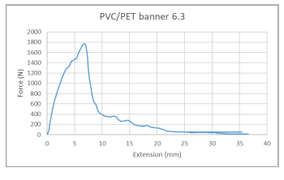


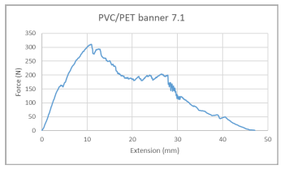


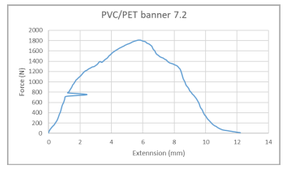


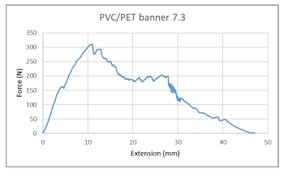








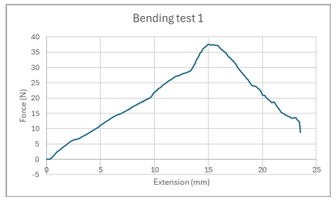




E.3 Bending test setup

The software was setup to measure with the following:
Sensor: 100 kg
Test type: Compression
Subtest: fail
Speed (mm/min): 2
X-axis: force
Y-axis: displacement

E.4 Bending test graphs



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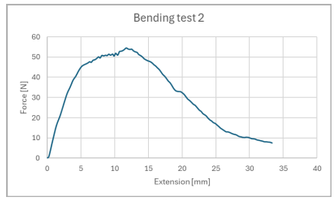

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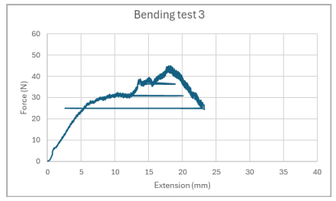

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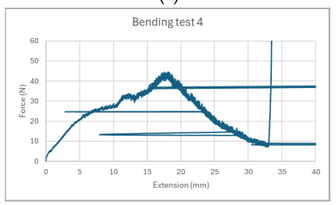

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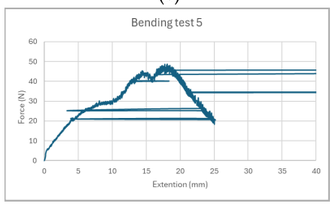

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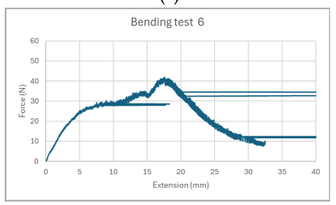


(f)

E.5 Bending test similar materials

Through the Granta EduPack data base a few charts were made to find materials which were similar in their values for Flexural strength and the Flexural modulus. You can find those below.

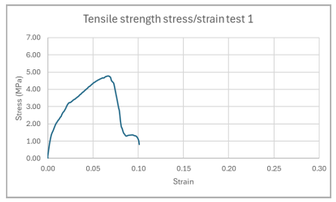
Flexural strength (MPa) Flexural modulus (GPa)

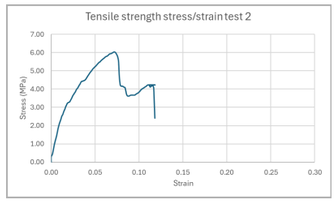
Name	X-Axis	Y-Axis
SBS (Shore A90/D40)	19.1 - 22.2	0.0976 - 0.103
PUR(r) (flexible, flame retarded)	6.8 - 22.2	0.104 - 0.581
TPV (PP+EP(D)M, Shore A90/D40, ...	24.6 - 27	0.133 - 0.147
PE-LD (molding and extrusion)	18.6 - 37	0.241 - 0.33
PE-LLD (molding and extrusion)	18.3 - 38.6	0.275 - 0.722
Polyester (cast, flexible)	14 - 29	0.293 - 0.308
PLA (ultra low modulus)	9 - 48	0.305 - 1.77
PVDC (copolymer, barrier film resin,...	25.8 - 28.4	0.345 - 0.552
PVDC (copolymer, injection)	29 - 42.7	0.378 - 0.653
TPU (Ester, aromatic, 20% glass fiber)	15.5 - 54	0.39 - 0.41
PVC (semi-rigid, molding and extrus...	7.57 - 28.2	0.408 - 0.691
PE (cross-linked, wire and cable gra...	14.4 - 30	0.537 - 0.564
PTFE (unfilled)	29 - 48.3	0.537 - 0.564
FEP (unfilled)	26 - 30	0.55 - 0.653
MFA (unfilled)	18.9 - 20.3	0.6
PVC foam (semi-rigid, closed cell, 0...	18 - 21	0.7 - 0.8
Plywood (3 ply, beech), perp. to fac...	25 - 40	0.7 - 1.1
PA66/6 (impact modified)	27 - 67	0.7 - 1.5
PE (cross-linked, molding)	20.4 - 44.8	0.7 - 2
PA612 (toughened)	24.8 - 30.3	0.735 - 0.88
SB (toughness)	18 - 25	0.772 - 1.19

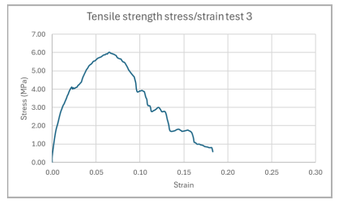
E.6 Tensile strength test setup

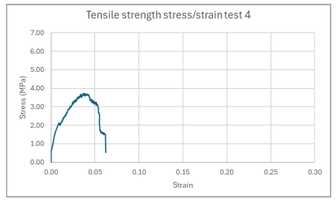
The software was setup to measure with the following:
Sensor: 100 kg
Test type: Tensile
Subtest: fail
Speed (mm/min): 10
X-axis: force
Y-axis: displacement

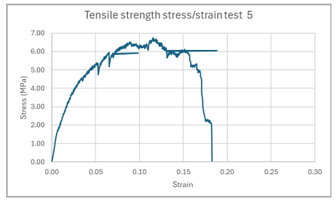
MATERIAL TESTING
E.7 Tensile strength graphs

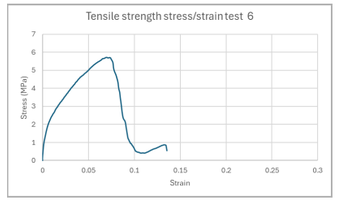


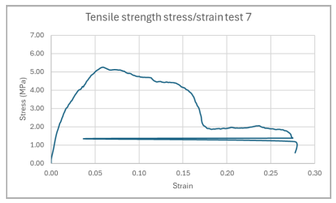


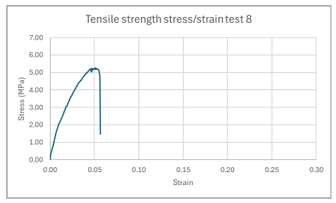


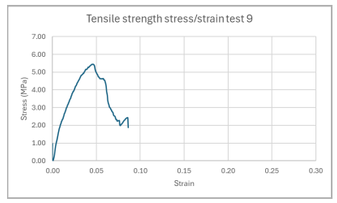


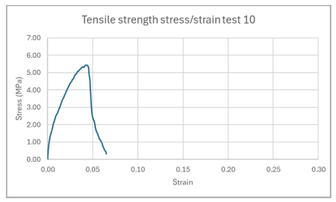


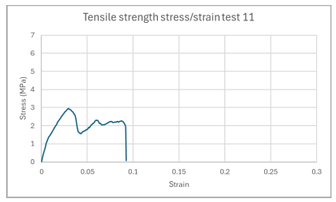










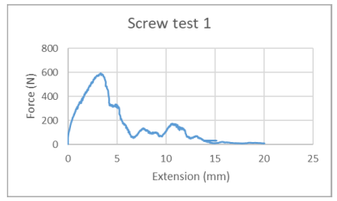


MATERIAL TESTING
E.8 Tensile strength test similar materials

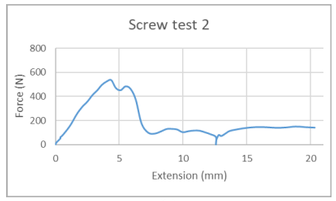
Through the Granta EduPack data base a few charts were made to find materials which were similar in their values for Young's modulus, yield strength and tensile strength. You can find those below.

- Polymethacrylimide foam (rigid, 0.110)
- Polyurethane foam (rigid, closed cell...
- PUR(r) (flexible, flame retarded)
- PUR(r) (mineral filler, flame retarded)
- PVC cross-linked foam (rigid, close...
- PVC cross-linked foam (rigid, close...
- PVC cross-linked foam (rigid, close...
- PVC cross-linked foam (rigid, close...
- PVC cross-linked foam (rigid, close...
- Styrene acrylonitrile foam (closed c...
- Styrene acrylonitrile foam (closed c...

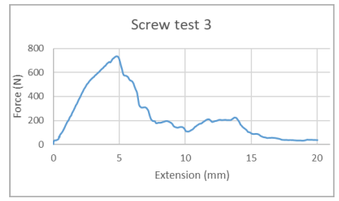
E.9 Screw pull test graphs



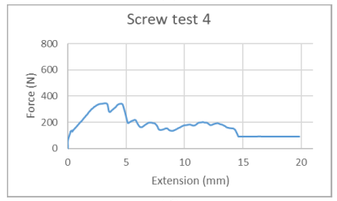
(a)



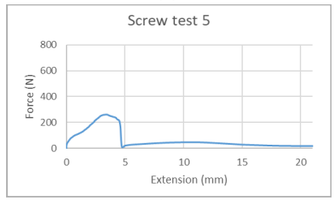
(b)



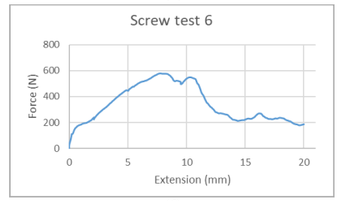
(c)



(d)



(e)



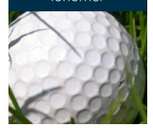
(f)

MATERIAL TESTING
E.10 Shore hardness test similar materials

Flexural modulus (GPa)

Al-70%Al2O3(Almax, f), transverse
Al6061-40%AlN(p)
Al6061-47%SiC(f), transverse
Al6061-50%B(f), transverse
Aluminum, 2008, T4
Aluminum, 2010, T4
Aluminum, 2010, T41
Aluminum, 2024, O
Aluminum, 2090, T83
Aluminum, 3004, H11
Aluminum, 3004, H32
Aluminum, 3004, O
Aluminum, 3103, H18
Aluminum, 3105, H14
Aluminum, 3105, H18
Aluminum, 443.0, sand cast, F
Aluminum, 5005, H16
Aluminum, 5052, H11
Aluminum, 5052, H32
Aluminum, 5052, O
Aluminum, 513.0, permanent mold c...
Aluminum, 5154, O
Aluminum, 5454, O
Aluminum, 5754, O
Aluminum, 6005, T1
Aluminum, 6005A, T1
Aluminum, 6016, T4
Aluminum, 6022, T4E32
Aluminum, 6060, T4
Aluminum, 6063, T4
Aluminum, A332.0, cast, T5
Aluminum, commercial purity, 1050...
Aluminum, commercial purity, 1200,...
Aluminum-polyethylene sandwich
Bismuth telluride
Brass, CuZn10Pb3Sn2, sand-cast
Brass, CuZn15As0.2, C23000, sand...
Brass, CuZn30Pb2, C85400, sand-c...
Brass, CuZn34Pb1, C34000, soft (le...
Brass, CuZn35Sn1, C85700, sand-c...
Brass, CuZn36Pb2, C35300, soft (le...
Brass, CuZn39Pb2, C37700, soft (le...
Brass, CuZn40, C85500, gravity die-...
Brass, CuZn40Pb2, C38000, pressu...
Brass, CuZn40Pb2Sn1, C85800, gra...
Brass, CuZn5, C21000, soft (gilding ...
Bronze, C93500, cast (leaded bronz...
Bronze, C93800, cast (leaded bronz...
Bronze, C94100, cast (leaded bronz...
Bronze, CuNi12Zn22Pb9Sn2, C9730...
Calcium, commercial purity, hard
Carbon (vitreous)
Carbon steel, SA216 (Type WCC), c...
Carbon/resin
Coated copper, copper, lead coated
Copper, C10100, soft (oxygen-free el...
Copper, C10200, half hard (oxygen-fr...
Copper, C10200, hot rolled (oxygen-f...
Copper, C10200, soft (oxygen-free h...
Copper, C10500, hot rolled (silver-be...
Copper, C10500, soft (silver-bearing ...
Copper, C12200, soft (phosphorus d...
Copper, C12500, soft (fire-refined tou...
Copper, C14200, soft (phosphorus d...
Copper, C14200, soft (tough-pitch ar...
Copper-cadmium alloy, C16200, soft...
Copper-Cd-Sn alloy, soft (h.c. copper)
Copper-Co-Be alloy, CuCo2Be, C17...
Copper-nickel alloy, C70400, soft (9...
Copper-sulfurous alloy, C14700, soft...
Copper-tellurium alloy, C14500, soft ...
Dysprosium, commercial purity, min...
Epoxy SMC (55% long carbon fiber)
Epoxy SMC (60% long glass fiber, fl...
Epoxy SMC (65% long glass fiber)
Epoxy/E-glass fiber, UD prepreg, U...
Erbium, commercial purity, min 99%
Femur trabecular bone
Gadolinium, commercial purity, min ...
Glass-ionomer
Gold, commercial purity, P00020, c...
Gold-germanium alloy, Au88 (12%G...
Gold-tin alloy, Au80 (80-20 solder)
Graphite (1.80)
Graphite (pure)
Holmium, commercial purity, min 99...
Lanthanum, commercial purity, min ...
Lithium fluoride
Magnesium, AM20, cast
Magnesium, AM60A, cast
Magnesium, AS41A, cast
Magnesium, AZ31B
Magnesium, AZ61A
Magnesium, AZ61A, cast
Magnesium, AZ80A, T5
Magnesium, AZ81A, cast
Magnesium, AZ91C, cast, T6
Magnesium, commercial purity, AST...
Magnesium, Elektron ZW3, F
Magnesium, EZ33A, cast, T5
Magnesium, ZC63A, cast
Magnesium, ZE41A, cast, T5
Magnesium, ZM21
Metal impregnated carbon
Mg-24%Al2O3(f), longitudinal
Mg-70%B(f), transverse
PA46 (50% glass fiber)
PA6 (50% glass fiber)
PA6 (50% long glass fiber)
PA612 (30% carbon fiber, 10% PTF...
PA66 (10% carbon fiber, 35% glass ...
PA66 (30% carbon fiber)
PA66 (40% carbon fiber)
PA66 (40% carbon fiber, flame retar...
PA66 (40% long glass fiber)
PA66 (40% long glass fiber, lubricat...
PA66 (50% glass fiber)
PA66 (50% long glass fiber)
PA66 (50% long glass fiber, lubricat...
PA66 (60% glass fiber)
PA66 (60% glass fiber, lubricated)
PA66 (60% long glass fiber)
PA66/6 (60% long glass fiber)
Palladium, commercial purity, P039...
Palladium, commercial purity, rolled,...
PARA (30% carbon fiber)
PARA (30% glass fiber)
PARA (50% glass fiber, flame retard...
PARA (50% glass fiber, toughened)
PEEK (30% carbon fiber)
PEEK (30% carbon fiber, lubricated)
PEI (20-25% nickel-coated carbon fi...
PEI (30% carbon fiber)
PEI (30% glass fiber)
PEI (30-40% nickel-coated carbon fi...
PEI (50% glass fiber)
PEK (20-30% carbon fiber)
PEK (30% carbon fiber)
PEKK (30% carbon fiber)
PESU (30% carbon fiber)
PET (30% glass fiber)
PET (45% glass fiber, recycled cont...
PI (30% carbon fiber)
PI (30% carbon fiber, crystallized)
Platinum, commercial purity, P0499...
Platinum-rhodium alloy, annealed, 3....
PPA (33% glass fiber)
PPA (45% glass fiber, flame retarded)
PPA (50% glass fiber)
PPA (50% glass fiber, lubricated)
PPA (50% long glass fiber)
PPA (51% glass and mineral)
PPA (60% glass fiber)
Praseodymium, commercial purity, ...
Radius trabecular bone
Resin impregnated carbon
Samarium, commercial purity
Selenium, commercial purity
Silver, commercial purity, fine, soft (...
Silver, P07931, soft (annealed), wire,...
Silver-Mg-Ni alloy, ELKONIUM 63, s...
Silver-nickel alloy, soft, wire, 10%Ni ...
Silver-nickel alloy, soft, wire, 15%Ni ...
Silver-nickel alloy, soft, wire, 30%Ni ...
Slate
Tantalum, commercial purity, R0520...
Terbium, commercial purity
Thulium, commercial purity
Tibia cortical bone
TPU(r) (40% long glass fiber)
TPU(r) (50% long glass fiber)
TPU(r) (60% long glass fiber)
Vanadium, commercial purity, annea...
Vertebrae trabecular bone
Ytterbium, commercial purity
Yttrium, commercial purity, soft
Zinc, commercial purity, Prime west...
Zinc-aluminum alloy, Alloy A, slush ...
Zinc-aluminum alloy, Alloy B, slush ...
Zinc-aluminum alloy, wire, 2%Al (sol...
Zinc-aluminum alloy, wire, 4%Al (sol...
Zinc-copper alloy, wire (fastener)
Zinc-copper alloy, Z40330, 0.8%Cu, ...
Zinc-copper alloy, Z44330, 1%Cu, ro...
Zinc-Cu-Mg alloy, Z45330, rolled
Zinc-Cu-Ti alloy, Korloy 3130, forged
Zinc-Cu-Ti alloy, Z41320, rolled
Zinc-lead alloy, Z21210, rolled
Zinc-Pb-Cd high alloy, Z21540, rolled
Zinc-Pb-Cd low alloy, Z21220, rolled

MATERIAL TESTING
E.11 Material comparison with similar materials

Properties.	Sign Again	Butyl rubber	Ionomer
			
Price	4.29-6.14 EUR/kg	2.26-2.39 EUR/kg	4.45-4.61 EUR/kg
Density	1400 kg/m^3	910-950 kg/m^3	934-950 kg/m^3
Young's modulus	90-270 MPa	0.7-1.5 MPa	100-380 MPa
Yield strength	2.00-5.30 MPa	2.4-10 MPa	15-19 MPa
Tensile strength	3.50-6.75 MPa	2.4-10 MPa	21-43 MPa
Flexural modulus	160-815 Mpa	0.7-1.5 MPa	100-380 MPA
Flexural strength	20-30 MPa	9.21-20.5 MPa	36.8-69.5 MPa
Hardness - shore D	49-61	2-8	56-66
Water absorption	0.4-3.38 %	0.01-0.02 %	-

Properties.	Leather	Cork
		
Price	14.6-18.2 EUR/kg	2.35-11.8 EUR/kg
Density	810-1050 kg/m^3	160-240 kg/m^3
Young's modulus	37.2-68.2 MPa	25-50 MPa
Yield strength	0.681-1.07 MPa	1.1-2.2 MPa
Tensile strength	1.28-2.47 MPa	1-2.5 MPa
Flexural modulus	62.5-96.6 Mpa	14-20 MPa
Flexural strength	0.681-1.07 MPa	1-2.5 MPa
Hardness	2-3 HV	1.2-1.6 HB
Water absorption	-	-

MATERIAL TESTING
E.12 Material comparison with similar industries

Properties.	Sign Again	FLOORING PVC	FLOORING Polyurethane rubber
			
Price	4.29-6.14 EUR/kg	1.19-1.64 EUR/kg	1.52-1.94 EUR/kg
Density	1400 kg/m^3	1290-1460 kg/m^3	1190-1210 kg/m^3
Young's modulus	90-270 MPa	2200-3100 MPa	2.5-30 MPa
Yield strength	2-5.3 MPa	37.6-45.5 MPa	40-51 MPa
Tensile strength	3.5-6.75 MPa	38-46 MPa	40-51 MPa
Flexural modulus	160-815 Mpa	2300-2960 MPa	2.5-30 MPA
Flexural strength	20-30 MPa	65-81 MPa	65-81.4 MPa
Hardness - shore D	49-61	77-83	12-41
Water absorption	0.4-3.38 %	0.04-0.4 %	0.2-0.22 %

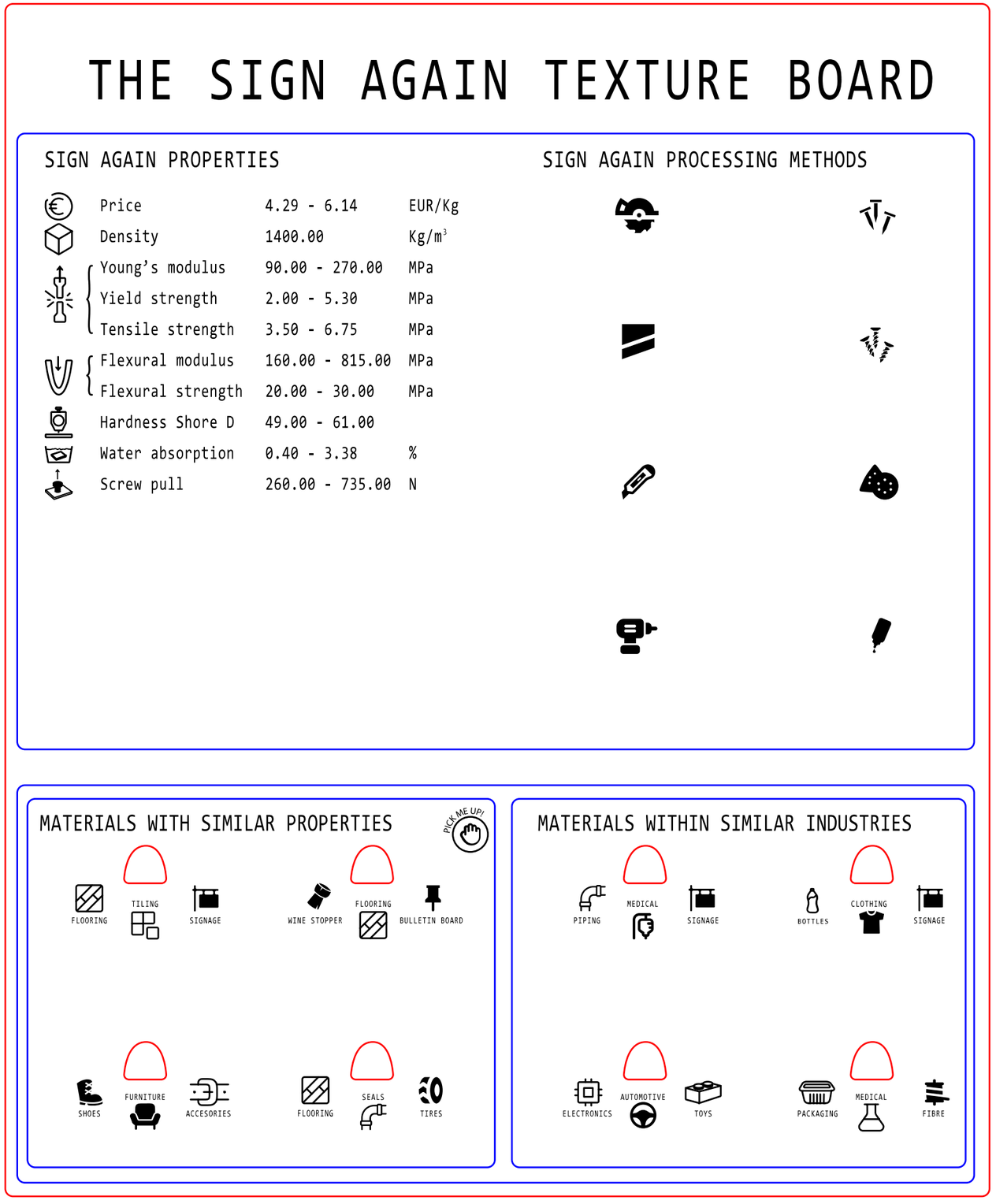
Properties.	SIGNAGE Polypropylene	TILING ABS	TILING Polyethylene (PET)
			
Price	0.984-1.29 EUR/kg	1.59-1.87 EUR/kg	0.738-1.43 EUR/kg
Density	899-908 kg/m^3	1020-1.080 kg/m^3	1370-1400 kg/m^3
Young's modulus	1340-1590 MPa	2000-2900 MPa	2760-3100 MPa
Yield strength	32.9-36.4 MPa	29.6-44.1 MPa	65-70 MPa
Tensile strength	33-42.9 MPa	30-50 MPa	70-75 MPa
Flexural modulus	1310-1590 Mpa	1200-2800 MPa	2990-3090 MPA
Flexural strength	29.9-60.2 MPa	40-80 MPa	70-75 MPa
Hardness	64-68 Shore D	9-13 HV	17-20 HV
Water absorption	0.0195-0.0205 %	0.2-0.45 %	0.1-0.2 %

DESIGN DEVELOPMENT
F.1 Ideation how to's

- How to convey information?
- How to convince people to change behaviour?
- How to reach people effectively?
- How to nudge people's behaviours?
- How to keep people's attention?
- How to communicate concisely yet complete?
- How to communicate visually?
- How to show people value in what was once seen as 'single use' products?
- How to get people out of stuck behaviours?
- How to get a tough conversation started?
- How to maintain sustainable behaviours?
- How to maintain behaviour change?
- How to raise awareness?

→How to communicate information to change and maintain people's behaviour to be more sustainable?

DESIGN DEVELOPMENT
F.2 Illustrator laser cut file



RESULTS DESIGN PHASE

G.1 Business model canvas: The Sign Again guidebook.

Partners

- Horizonteer
- Material testing labs
- Sign again production facilities
- Policy makers

Key activities

- Continuous material testing and data updates
- Translation of LCA data into storytelling
- Stakeholder workshops
- Maintaining the strategic roadmap

Key resources

- Proprietary test data
- Design expertise
- Knowledge of the PVC/PET value chain
- the revised theoretical framework

Value propositions

- Provides transparent, comparable and actionable material data
- Translates complex technical testing into designer friendly metrics
- Enables circular storytelling for B2B clients
- Reduces percieved risk in sustainable procurement

Customer relationships

- Professional authority: building long-term trust through scientific transparency. Acts as a boundary object that facilitates communication between technical suppliers and create clients.

Channels

- Digital PDF distribution via the Horizonteer, IGEPA and PROBO websites
- Physical copy attached to the texture board, available during company visits or venues

Customer segments

- Procurement officers at large venues
- Print shop managers
- Sustainability consultants
- B2B marketing departments looking to validate their green claims

Cost structure

- Research and testing hours
- Graphic design and copywriting
- Digital hosting and physical printing costs

Revenue stream

- Integrates into Horizonteer's consulting fee, sold as asset
- For IGEPGA and/or Probo it can be added to material orders and
- a potential signage as a service subscription model can be set up

RESULTS DESIGN PHASE

G.2 Business model canvas: The Sign Again texture board

Partners
- Sign Again producers
- Ehibition organisers

Key activities
- Fabrication of physical boards
- Sourcing o samples
- Assembly of the board
- Distribution to key leads

Key resources
- Physical material samples
- Manufacturing equipment for the boards
- Branding

Value propositions
- Provides transparent, comparable and actionable material data
- Translates complex technical testing into designer friendly metrics
- Enables circular storytelling for B2B clients
- Reduces percieved risk in sustainable procurement

Customer relationships
- Sensory engagement: physical interaction that makes the circular transition easier. It provides a tangible proof of concept during the discover/define stages of design

Channels
- Direct sales/pitch meetings
- Design trade shows and circularity exhibitions
- Material libraries
- Showroom displays

Customer segments
- Interior designers
- Exhibition architects
- Event planners who require physical samples for mood boards and structural validation

Cost structure

Revenue stream
- Indirect revenue as a sales tool for Sign Again
- Physical asset included in circular starter kits for new partners

Conflict of interest
The author declares no conflict of interest. This thesis was conducted with support of a company, Horizonteer. The company did not influence the results or conclusions presented in this work. All presented views reflect those of the author and involved individuals.

Statement on AI use
This thesis benefited from the use of AI tools (e.g. Gemini) for language refinement and feedback generation. All content and conclusions are the author's own and critical analysis was performed independently.

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