The Centre for Sustainable Design®

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Director of Sustainability, Decathlon UK

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Kings College

Daan van der Wekken
Head of Sustainability, BSI

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Mission: Planet - Harnessing Compound Interest and Token Economics to Fund Climate Action at Scale

Keiron Allen

Founder

Mission:Planet

France

The climate crisis demands unprecedented mobilisation of capital, yet traditional funding approaches have proven insufficient. Mission:Planet introduces a revolutionary model that combines the power of compound interest with innovative token economics to create a self-sustaining engine for climate action funding.

At its foundation, Mission:Planet is structured as a trust with the planet as its sole beneficiary in perpetuity. This unique structure ensures complete alignment between financial returns and environmental impact, while eliminating conflicts of interest inherent in traditional corporate structures. The trust operates through two distinct but complementary business streams: pure profit-generating enterprises (such as banking and financial services) and profitable net-zero businesses (including renewable energy, sustainable transport, and forestry operations).

The model's transformative power lies in its application of compound interest – Einstein's "eighth wonder of the world." By reinvesting profits from both business streams back into growth and climate action, Mission:Planet creates an exponential growth cycle. This is further enhanced by the trust's commitment to employing top talent, offering compensation in the top 10th percentile to attract and retain the best minds in sustainable innovation.

To rapidly scale this model, Mission:Planet introduces the M:P token - a smart cryptocurrency with initial minting of 1 trillion tokens at $1 each. This innovative tokenization approach effectively doubles the economic impact: while 100% of the proceeds fund climate action through the trust's businesses, token holders retain value through their M:P holdings. The token's price stability is maintained through a sophisticated mechanism tied to the underlying business value, with a 65% loan-to-value ratio providing a robust price floor.

Project selection follows a rigorous process: Source (identifying shovel-ready projects), Select (evaluating speed and impact potential), Decision (trustee voting), Execution, and Measure (comprehensive impact reporting). Crucially, while Mission:Planet measures success through environmental impact, it explicitly embraces "Profit for Good" - targeting 80% of projects to have strong commercial fundamentals, ensuring perpetual funding capability.

The token's mintable, burnable, and governance capabilities provide additional economic controls, while the trust structure ensures all value creation serves the planet's interests. This creates a virtuous cycle where environmental protection drives profit, and profit enables greater environmental protection.

Mission:Planet represents a paradigm shift in climate action funding, moving beyond traditional philanthropy or government funding to create a self-sustaining, profit-driven model that can scale to meet the climate crisis. By combining the power of compound interest with innovative token economics, it offers a practical path to mobilizing the trillions needed for effective climate action while providing investors with a compelling value proposition.

This paper presents the theoretical underpinnings, practical implementation, and potential impact of the Mission:Planet model, demonstrating how financial innovation can help solve our most pressing environmental challenges.

The Design Compass®: Evaluating a New Tool for Senior Product Design with Students

Simon Andrews
Course Leader/Senior Lecturer
Falmouth University
United Kingdom

Evy Dutheil
Senior Lecturer
Falmouth University
United Kingdom

Rebecca Falcon
Senior Lecturer
University of Chester
United Kingdom

Stefan Knox
Creative Director
Bang Creations Ltd
United Kingdom

Abstract

The Design Compass is an online tool to support the development of commercially viable products whilst navigating environmental sustainability and social impacts. Undergraduate Product Design students from Falmouth University and the University of Chester used the Design Compass throughout a taught module. The project saw cross-institutional collaboration between students, academics, and the Design Compass developers, Bang Creations Ltd. Qualitative research focused on feedback provided by the students on their experience of using the tool, their design process and outcomes developed. The study provides a positive indication of the benefits of the Design Compass in a learning and teaching context, and advantages over other eco-design tools. Student feedback was also helpful in providing suggestions for improvements for the tool. Some of these suggestions have already been implemented by Bang Creations in a later iteration of the Design Compass.

Introduction

The Design Compass is an online tool to support the development of commercially viable products whilst navigating environmental sustainability and social impacts. It has been developed by B-Corp design consultancy, Bang Creations Ltd. They have already used an earlier version of the tool to develop products such as the Alora sustainable baby crib (Bang Creations 2025). More recently they have partnered with Falmouth University and the University of Chester to develop the Design Compass further.

This paper reports on an initial pilot study to explore the value of using the Design Compass in higher education. To gather feedback on the usability and effectiveness of the Design Compass, the tool was integrated into 2nd year taught modules on the BA(Hons) Sustainable Product Design course at Falmouth University and the BA(Hons) Product Design course at the University of Chester. Both courses had independently worked on live project briefs supported by Bang Creations in the past, but this project presented an excellent opportunity to extend the collaboration as a cross-institutional approach.

Background

When developing new products, or improving existing designs, tools such as the Life Cycle Design Strategy (LiDS) wheel (Brezet and Van Hemel 1997) and the Okala Ecodesign strategy wheel (Okala 2012), are used by designers to explore opportunities to reduce environmental impacts across the life cycle of the product. For global sustainable development, the 'Three Pillars of Sustainability' (Brundtland 1987) highlight the need to consider the interrelated social and economic impacts as well as environmental impacts.

Figure 1: The Design Compass.

The Design Compass (Figure 1), an online tool for people engaged in bringing a physical product to market, helps to navigate these three interrelated issues simultaneously. It differs from existing tools by emphasising design decisions to support a commercially viable product whilst navigating environmental sustainability and social impacts. The tool is comprised of three circular layers that represent design for social, environmental, and economic sustainability. Each layer is segmented into six questions designed to provoke, challenge, and inspire the development of sustainable design concepts, whilst providing actionable guidance (using written and visual prompts, and links to other resources) on how to address the challenges.

The economic layer (centre) of the tool investigates what is needed to bring a successful product to market. Here the focus is on critical business strategies relating to customers and manufacturing. The environmental layer (middle) prompts eco-design strategies that can be considered across the lifecycle of the product. Examples include exploring energy consumption, material selection, durability and repairability. The social layer (outer) probes the meaningfulness of the product and the value it can bring to society. Here the focus is on inclusivity, equality and social justice.

Figure 2: Using the benchmarking feature.

The tool is unique as it has three distinct uses: providing a structured framework for learning sustainable design strategies; generating innovative ideas and evaluating them through the questions across the three layers; and benchmarking design concepts against industry standards (Figure 2). Through the online user interface, the circular layers can be rotated so numerous combinations of three questions (relating to social, environmental and economic sustainability) can be aligned and explored together. This feature of the tool reveals the tensions that can exist between business priorities and the needs of people and planet.

Methodology

The Design Compass was introduced to both student cohorts at the beginning of their respective design modules (see timeline in Figure 3). Fourteen students were enrolled on the module at Falmouth University and eight at the University of Chester. Product design outputs were required from both modules, and the students were given identical design briefs to tackle. The Falmouth module explores the Circular Economy whilst the Chester module focuses on developing commercially viable products. The pairing of these modules conveniently reflects the ambition of the Design Compass to help designers bring sustainable products to market. The shared brief facilitated cross-institutional collaboration but also provided comparability on how the students used the Design Compass and equivalence on the feedback generated. The brief asked the students to engage holistically with the Design Compass, by exploring lighting design concepts for the circular economy.

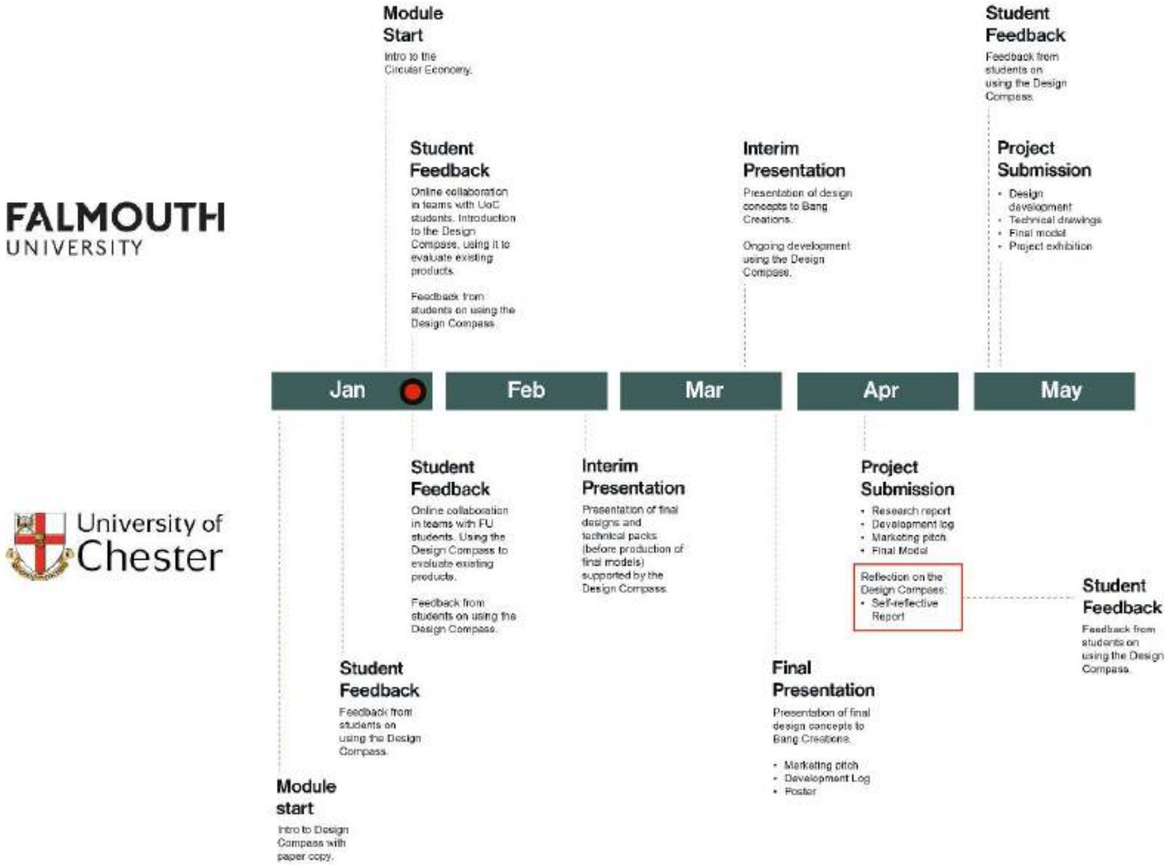

Figure 3: Project timeline for module activities.

Qualitative research was conducted at the beginning and end of the project. The student feedback reflected on the Design Compass in response to three specific questions:

- How have you used the Design Compass?
- What did you find most useful about the Design Compass?
- What would you change to improve the Design Compass?

The students' responses were collated and coded to analyse the frequency of themes reported (Huberman and Miles 1994). This quantitative approach provided a measure of the most common themes, although there is no statistical significance due to the small sample size. Another limitation in the approach was that the Chester students started their module two weeks earlier than the Falmouth students so the initial feedback on the Design Compass was only from this cohort. At this stage, they were introduced to the tool in a printed paper format. The introduction to the Design Compass for the Falmouth students coincided with the collaborative workshop where both cohorts evaluated the tool together.

At the end of the module the course teams were able to review how the students had engaged with the Design Compass through the work submitted for assessment. In particular, the way in which the students had used the tool to learn sustainable design strategies, generate and evaluate design ideas, and how effectively they had benchmarked their concepts against existing products. Further student feedback was gathered through a self-reflective report written by the Chester students.

To ensure the research was conducted ethically, all the students were provided with participant information sheets that described the project and their anticipated involvement with the research. The academics talked through the participant information with the students before they signed consent forms. As Falmouth University led the research, the project received research ethics approval from Falmouth University's Research Integrity & Ethics Committee (RIEC).

Findings

The students responded to the design brief with a range of innovative lighting concepts. There was good evidence of engagement with the Design Compass to inform the design process. Their responses to the questions were as follows:

How have you used the Design Compass?

Across all stages of the project, the students most frequently reported that they used it to 'generate ideas' and 'evaluate ideas' (see Table 1). The ability to use the tool to initiate new concepts and consider the viability of existing ideas against the three layers, was particularly highlighted.
Across the collaborative and final stages of the project, the students noted how they had used it to 'evaluate existing' products. This preceded using the tool to benchmark their design ideas against competitor products. At the final stage of the project, more emphasis was placed on using the tool to 'refine concepts'. A student noted that they had used the Design Compass, "…to help to advance some of my more final ideas, to ensure that I had thought about every aspect". At this stage too, students noted how they had 'benchmarked concepts' using the tool, for example to, "…evaluate against existing ideas and explore the market".

Table 1: Coded responses collated for question 1

#	How have you used the DC? - Coded responses	Code Frequency (n)
1	Generate ideas	16
2	Evaluate ideas	10
3	Refine concept	7
4	Question prompt	6
5	Evaluate existing	5
6	Benchmark concept	5
7	Sustainable design	2
8	Track progress	2

What did you find most useful about the Design Compass?

Although the students had used it to benchmark their concepts against existing products, few of the students identified this as the most *useful* feature. Instead, using the tool to 'generate ideas' was deemed most useful across all stages of the project (see Table 2).

Table 2: Coded responses collated for question 2

#	What did you find most useful about the DC? - Coded responses	Code Frequency (n)
1	Generate ideas	10
2	Question prompt	9
3	Reframe ideas	6
4	Social layer	4
5	Evaluate ideas	3
6	Consider product impacts	3
7	Environmental layer	2
8	Refine concepts	2
9	Benchmarking	2
10	Improve design	2
11	Identify gaps	2
12	Economic layer	2
13	Widen knowledge	1

14	Creative thinking	1
15	Framework	1
16	Discussion	1
17	Intuitive design	1
18	Interactive	1
19	Beyond eco sustainability	1
20	User centred	1

Similarly, 'reframe ideas' was when it had forced the students to think differently in ways they had not expected. For example, one student noted, "I found it useful to take questions that I usually wouldn't ask towards my ideas and from that it helped me think more outside of the box". Indeed, the 'question prompts' were seen as a useful guide throughout the process. However, although the Design Compass UI provides detailed written and visual information that unpacks the meaning of the questions, there was no specific feedback from the students on how useful this information was to them.

What would you change to improve the Design Compass?

Most responses were unique suggestions for improving the UI, such as 'colour code the layers', 'optimise for smart phone', and 'customise UI colours' (see Table 3). Bang Creations have carefully reviewed these suggestions and, where appropriate, have factored them into ongoing development of the Design Compass. For example, the suggestion for a 'light and dark mode' to improve readability and reduce eye strain in varying light conditions has since been implemented.

Table 3: Coded responses collated for question 3

#	What would you change to improve the DC? - Coded responses	Code Frequency (n)
1	Colour code the layers	3
2	Light and dark mode	3
3	Wheel layout	2
4	Guidance on Benchmarking/ colour	2
5	Questions more applicable to early ideation	1
6	Remove shadows for easier cut out (paper)	1
7	Typo on paper version	1
8	Bolder key words	1
9	More colour	1
10	Open source	1
11	Optimise for smart phone	1
12	Menu font legibility	1
13	Title the prompts on Idea Generator	1
14	Rotatable layers on Benchmark	1
15	Rotate to only Customer or Manufacture on Idea Generator	1
16	Insert reference product image	1
17	Customise UI colours	1
18	Customise UI font size	1
19	Integrate all three layers	1
20	Save Benchmarks on website	1
21	Second wheel for Benchmark comparison	1

Students suggested changes to the benchmarking tool, shown through 'guidance on benchmarking/colour', which was also indicative in some of the final projects submitted. A student commented that they needed, "…more information with the benchmarking as I was unsure what colour to put on some of the questions". Another student felt it would be helpful to have a, "…second wheel for the comparison product in the benchmark tool". These responses reflect the earlier observation that the students found the idea generation feature, prompting sustainable innovation, more useful than the benchmarking tool.

Further to the evaluation of student feedback, three other critical areas were explored by the course teams:

A framework for learning sustainable design strategies

Sustainable design strategies are a core part of 1st year teaching at Falmouth, so the students were familiar with the principles presented in the social and environmental layers of the tool. At Chester, sustainable design is introduced in the curriculum through this module, so to build their contextual awareness and vocabulary, the students needed to explore a variety of sustainable design models before adopting the Design Compass. A paper version of the tool proved particularly effective (Figure 4), helping students to connect more actively by having the compass in-sight and in-mind throughout the design process.

Figure 4: A paper version of the Design Compass created by a University of Chester student.

Initial discussions with Chester students revealed mixed attitudes toward sustainable design. Some had a desire to engage with sustainability, while others viewed it as a superficial tick-box exercise. However, reflections at the project end evidenced a significant shift in mindset. One student admitted, "If I were to design my product again, I would make sure to use the Design Compass all the way through rather than at the end… I learned how truly important sustainability is when creating a product in the 21st century."

Idea generation and evaluation

The three layers of the Design Compass were discussed through group reviews of the concepts which helped students to evaluate their ideas, especially through the lens of the environmental and social layers (Figure 5). Chester student feedback on the idea generation aspect noted the tool's ability to “spark conversations and new ideas” to “think more outside of the box” and “see where the concept was lacking”.

Figure 5: Peer review of concepts using the Design Compass at University of Chester.

The students used the idea generation feature of the Design Compass UI to produce randomised sets of questions across the three layers. For example, a Falmouth student generated four separate interpretations during the early concept development stage (Figure 6). The triangular sections represent a portion of the three layers replicated by the student in their sketchbook. They reflected through sketches in response to themes including, ‘interactive features’, ‘recyclability’, ‘repair’, ‘maintenance’ ‘long-lasting’, and ‘renewable energy’. The social aspect is suggested with ‘communities’ and ‘safety’, but this could be developed further.

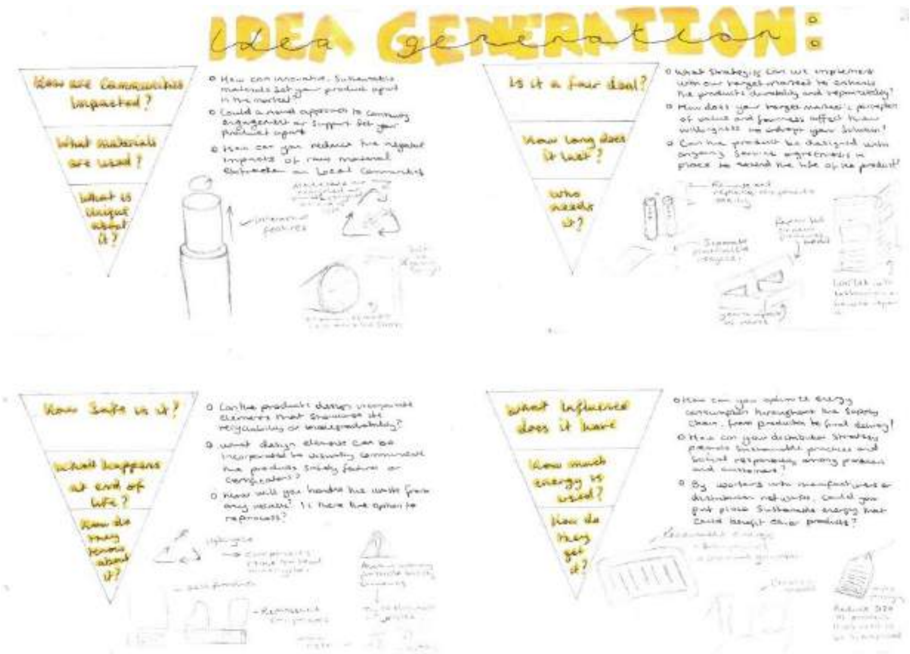

Figure 6: Idea generation prompts explored by a Falmouth University student.

In another example, (Figure 7), a Falmouth student used the Design Compass to evaluate the ‘good’ and (industry) ‘standard’ areas of their concept and prototypes. They used a colour key applied to the selected section on each layer. The sketchbook page demonstrates analysis of a concept model with annotations. This process supported better decision making, leading to the development of three main design concepts.

Figure 7: Falmouth University student's concept model evaluation using the Design Compass

Benchmarking design concepts

To support benchmarking activity the students investigated existing manufactured products. For example, Falmouth students were supported by the university’s BSc Robotics course to help understand the electrical componentry in a lighting product. To build the skills and experience needed to design for manufacture, Chester students participated in hands-on disassembly activities. Using the design compass as a discussion tool, students assessed the relative sustainability of the products disassembled and later applied those evaluative skills to their own designs.

Figure 8 shows an example of how a Falmouth student used the benchmark tool, including reflective comments on their design concept. Presented in their sketchbook, they used the key colour to score the against the criteria. They also did a comparison with four existing products, using the idea generation feature of the Design Compass, to focus on three questions in the analysis of the product.

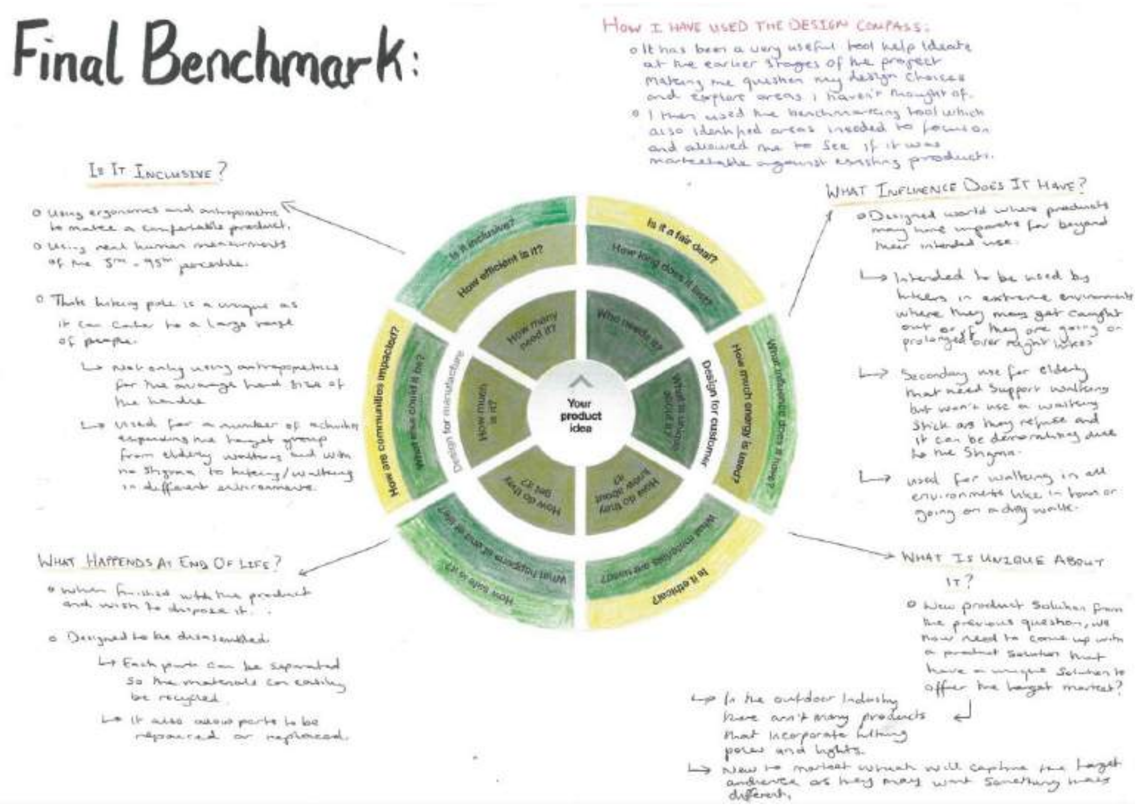

Figure 8: Falmouth University student design concept benchmarking.

A progression in the use of the Design Compass was demonstrated in most of the students' work. Students responded to fewer of the questions on the Design Compass in the early design stages. In later stages, they presented a richer engagement with the three layers, demonstrated through a colourful assessment of their project.

Although the students reported that benchmarking their ideas against existing products was challenging, the process facilitated critical reflection and group discussions. Regardless of the accuracy of the coloured segments, this was a valuable learning activity, and the conversations demonstrated an increased maturity of understanding. An example of critical reflection using the benchmarking tool by a Chester student is shown below (Figure 9).

Figure 9: University of Chester student design concept benchmarking.

Discussion

The Design Compass encouraged holistic thinking by prompting students to consider not just aesthetics and user experience, but also environmental and social impacts. This encouraged a more rounded approach to design: for the Chester students who were at an earlier stage of learning about design and sustainability, and the Falmouth students who had focused less on commercial viability. Although all the students found it challenging to navigate all the environmental and social sustainability questions, the tool nurtured their understanding of sustainable design and helped them to consider the overall impacts. This also demonstrated an ‘ownership’ of their learning and confidence in considering the sustainability credentials of their project alongside business strategy. For example, the question prompts helped the students to think more critically about their own work, become more objective and less invested in a personal creative agenda. Module tutors felt this was helped by the questions coming from the tool, not just them.

The students found using the Design Compass to help generate ideas its most valuable feature. This was most apparent when they worked together to evaluate their concepts. Group sessions using the Design Compass’s idea generation function were particularly effective in sparking discussion and new ideas. The tool provided a structured way to approach problems and move design concepts forward. The questions provoked the students into new ways of thinking, whilst the interactive feature – where three questions across the three layers align to become the focus – is a particularly playful aspect of the tool.

The tool also helped to bridge the gap between creative idea generation and the marketability of products. When Bang Creations have supported student workshops, they have observed that the students come with strong creative ideas but often lack an understanding of what makes a product commercially viable. The Design Compass helped them consider business models and market needs from the outset, reinforcing that only marketable products progress to development.

The benchmarking tool was popular for its visual impact and was included in student presentations. However, they requested more guidance on how to interpret and justify their benchmarking choices. The benchmarking tool invites critical thinking, but without an in-depth knowledge of comparative products, some students struggled with it. The benchmarking UI offers a convenient way of colour coding the questions. Notably, in the Falmouth cohort, students who physically reproduced the Design Compass in their sketchbook, demonstrated a deeper level of reflection, unpacking their thought process on each section.

Other sustainability models used by the students include the 'Three Pillars of Sustainability' (Brundtland 1987); Life Cycle Design Strategy (LiDS) (Brezet and Van Hemel 1997); The Butterfly Diagram (Ellen MacArthur Foundation 2021); methods from the Circular Design Guide (Ellen MacArthur Foundation 2016); Okala Ecodesign Strategy Wheel (Okala 2012); and Emotionally Durable Design Nine (Haines-Gadd et al. 2018). The Design Compass differs and 'adds value' to the existing tools by:

- Integrating business strategy and sustainable design thinking into one project-focused design tool.
- Supporting sustainable design innovation through an engaging and interactive online tool, particularly the idea generation and benchmarking features.
- Integrating resources and supporting material into an online tool, directly responding to the question prompts, to provide actionable guidance to support informed decision making.

Conclusion

The Design Compass prompted deeper critical thinking and helped students adopt a systems-thinking approach to sustainable design. Academics from both courses observed improved decision-making and greater confidence when discussing sustainability strategies. By embedding the Design Compass early in the process, students shifted from abstract innovation to an emphasis on viable, sustainable solutions, fostering a more sophisticated understanding of their role and impact as designers.

The tool is designed to encourage iterative, circular design thinking and project-focused learning. Students learn best through doing, and the Design Compass supports this by challenging them at every development step. Ongoing collaboration with academia and iterative tool development will ensure it continues to support effective learning and innovation in product design.

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Sustainable Innovation: Past, Present and Future

Mike Barry

Co-Founder

Planeatry Alliance

United Kingdom

Over the past 25 years, businesses have made some progress in sustainability, but true transformation remains limited to sectors such as energy and transport. Despite a favourable global context between 2000 and 2025, the world has failed to curb rising consumption and emissions. Increasing global instability now complicates the urgent task of reshaping economies within planetary boundaries. A rethinking of sustainability is needed through five key areas: clearer value creation, broader focus beyond carbon, stronger partnerships, simpler sustainable choices, and the use of digital innovation. Although halfway to 2050, only about 10% of the necessary progress toward a sustainable future has been achieved.

Over the last 25 years a number of businesses have sought to take a lead on environmental issues. They have set bold goals and made significant strides in low carbon and circular economy materials and business models.

But, apart from the power (fossil to renewables/storage) and automotive (diesel/petrol to electric) sector transformations, which themselves have a very significant distance to travel, little has been done to stem the tide of growing population, consumption, emissions and impacts.

This failure to act in the period 2000-2025 is particularly damning given that for at least two decades of it there was a reasonably benign political, societal and economic backdrop against which to fashion and deliver transformative global change.

With hindsight 9/11 and the wars it spawned; the financial crash of 2008; Putin's seizure of Crimea in 2014; and Brexit and the first Trump Presidency in 2016; were all signals that the stability of the wider period of 1980-2020 was coming to an end.

Today we face a period of global uncertainty unparalleled since the end of WWII eighty years ago whilst having to engineer a profound re-alignment of the global economy to fit within the finite boundaries of society and the planet.

For now, despite growing political pressure, there has not been, a wholesale roll back of corporate commitments on environmental and social issues. But, we need to very clear, there is no 'golden period' of the near past when 10000s of companies were actively reducing their social and environmental footprints through business model, product/service and value chain innovation. There were plenty of speeches, press releases and reports but far less action.

So, whilst those who oppose change can take much of the blame for the planet and society's ills, they cannot be held wholly accountable for the predicament we find ourselves in. The sustainable business movement (in business, academia, investment, civil society and policy) needs to reflect and act on a narrative (Net Zero, SBTI, CSRD etc) that never succeeded in triggering a mass embracing of sustainability across their ecosystems.

If we are to succeed in our desire to create a liveable future for close to 10 billion people by 2050 we need to re-think profoundly our approach to a sustainable future through 5 specific lens – clearer value creation; escaping the 'carbon tunnel'; building new approaches to partnership; simplifying making better choices; and using the surge in digital innovation as enabler of transformative change.

From the temporal perspective of 2000, we are halfway to 2050 but in terms of what we need to do to secure a liveable future we are barely 10% along the path. We must find a better way to communicate and deliver sustainable transformation.

Climate Change, Net Zero and Product Decarbonisation

James Cameron

Senior Advisor to Pollination Global

Non-Executive Director of Octopus Renewables Infrastructure Trust (ORIT PLC)

United Kingdom

The evolution of the climate change debate from origins in state responsibility through international negotiations and the formation of an enterprise response. Connecting law, policy, finance and technology to problem solving over nearly 40 years provides experience and reserves of confidence in the power of innovation. Examples from past and present provided. Curiosity and openness to the new and different provides regular bursts of optimism in the face of daily assaults on knowledge and capricious use of power. An intergenerational conversation about climate change is necessary and productive; diverse powers can be combined, and passion, energy and resources better deployed. The transition cannot happen without imagination; thinking differently, doing differently and winning competitively. There must be pride in place and community, joy in the experience and life must get better having done the work.

Ensuring Trust in Sustainability Claims: Standards, Compliance, and Industry Impacts under the European Green Deal

Raul Carlsson

Senior Researcher

RISE Research Institutes of Sweden

Sweden

Tatiana Nevzorova

Senior Researcher

RISE Research Institutes of Sweden

Sweden

Abstract

This research aims to analyze different requirements for the verifiability of sustainability-related claims and statements made or proposed by the European Commission, international and European standards and business agreements developed to guide organizations, local actors, national and international trade and markets, as well as examples of certification schemes relevant to challenges handled by the process industries. To ensure relevance and practical guidance, real cases of sustainability statements and claims were studied in process industry companies, regarding how to interpret, express, and set requirements for verifiability and substantiation of sustainability claims. Though the Green Claims directive focuses on claims targeted to consumers, this research considers the implications of this directive for business-to-business sustainability information sharing. This article also includes an extensive literature study presenting directives, standards, and other literature relevant to the subject of sustainability claims and green claims.

Introduction

The EU Commission's proposal for the European Green Deal (EGD) expresses trust in market forces, including citizens' willingness to make sustainable choices in their private lives and business decisions (European Commission, 2019a). The driving force behind the verifiability of sustainability claims is the necessity to provide consumers and professional decision-makers whether motivated by personal commitment or professional obligation, to make decisions promoting sustainable development—with factual sustainability-related information. At the same time, there is a fear that due to the complexity and amount of sustainability information, it becomes an overwhelming burden for companies to acquire the data needed from different stakeholders to form the information and formulate such statements and claims that are both compliant with regulatory requirements and with scientific scrutiny while at the same time be understood by their customers. The consequences for the industry from these new requirements are yet difficult to foresee.

The Green Claims Directive (GCD) states that, according to the European Commission, more than half of the environmental claims evaluated in a recent market survey were vague, misleading, or unfounded, and a significant portion lacked appropriate substantiation (European Commission, 2023a). Such findings highlight a substantial gap between public sustainability communication and verifiable, science-based data. Companies face a dual challenge: to meet increasing stakeholder demands for transparency while navigating complex regulatory, technical, and communicative requirements. The implications extend beyond consumer-oriented claims to business-to-business (B2B) settings where contractual, financial, and reputational risks linked to sustainability statements are growing.

This article presents an integrative analysis of the current policy landscape, international and European standards, and practical examples from process industries. Since a 'verifiable sustainability claim' refers both to how to verify that a sustainability claim is correct and how to form and formulate such a claim, this research includes both perspectives on the subject by presenting and discussing questionably verifiable claims together with guidance on how to better form and formulate them.

Background

Regulatory framework under the European Green Deal

Sustainability claims are increasingly central to corporate communication, consumer engagement, and regulatory compliance. The European Green Deal (EGD) (European Commission, 2019a) aims to ensure that citizens and market actors can trust sustainability claims made by companies across sectors. The proposed Green Claims Directive (GCD) (European Commission, 2023a) is a core initiative within this broader policy framework, designed to counter greenwashing and reinforce confidence in environmental labeling and reporting.

The GCD proposal requires companies to substantiate explicit environmental claims using standardized methodologies and to subject them to third-party verification (European Commission, 2023a). The GCD defines environmental claims broadly, covering all forms of communication about a product's or organization's environmental performance. The proposal targets several misleading practices: vague terminology (e.g., “eco-friendly”), unverified carbon neutrality claims, and generic sustainability statements that lack precise scope or evidence. To comply, organizations must support their claims with relevant scientific evaluation, such as peer-reviewed lifecycle assessments (LCA), product carbon footprints, or other appropriate verifications supporting the scope of the claim. The GCD also restricts the use of comparative claims unless the basis of comparison and methodology is made explicit. Importantly, the directive mandates that consumers have digital access to the verification and substantiation behind any claim, using mechanisms such as QR codes on packaging.

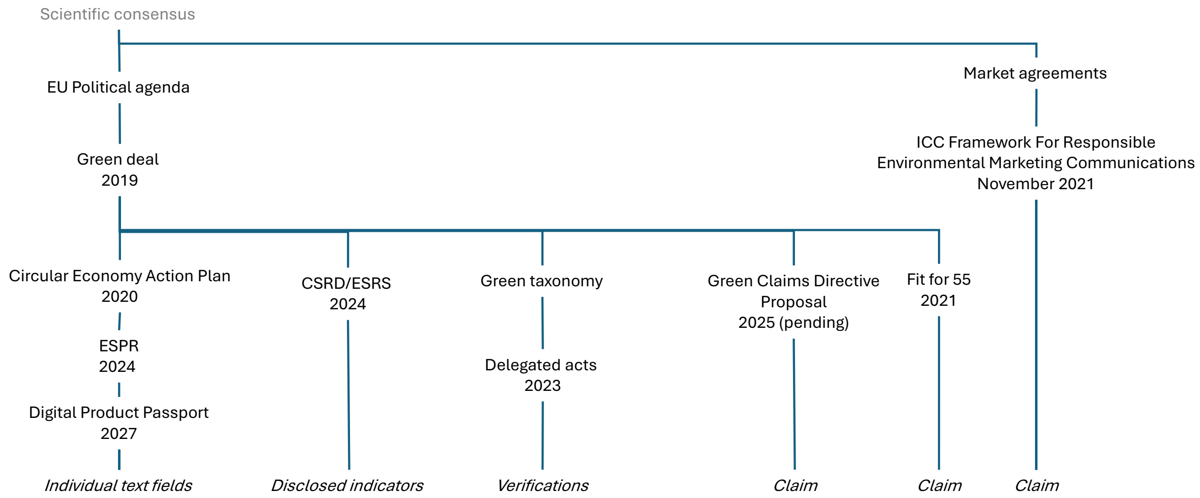

Figure. 1 Schematic overview of relationships between and implementation dates of scientific and business consensus, EU Political agenda and EU implementation strategies.

Figure 1 presents a schematic overview of how scientific, market, and policy instruments interrelate. Several existing or planned EU policies reinforce the GCD and include the following:

- *Corporate Sustainability Reporting Directive (CSRD),* which requires large and listed companies to disclose ESG information, supported by the European Sustainability Reporting Standards (ESRS) (European Commission, 2022; European Commission (2023b).
- *Ecodesign for Sustainable Products Regulation (ESPR)* that introduces a Digital Product Passport (DPP) system for forwarding and tracking sustainability-related data across product life cycles (European Commission, 2019b).
- *EU Taxonomy for Sustainable Finance*, which classifies economic activities based on environmental sustainability criteria, promoting standardization in green investments (European Commission, 2020).

- *Fit for 55 Initiative* enforces emissions reductions in line with the EU's climate neutrality goal by 2050, further driving the need for reliable environmental data (European Commission, 2021).

Together, these instruments form an interconnected policy matrix that elevates the importance of verifiable sustainability information in public and private decision-making.

Figure. 1 also mentions the International Chamber of Commerce Framework for Responsible Marketing Communication (ICC, 2021). It provides an international global standard for ethical and responsible commercial marketing practices, ensuring that advertising and promotional activities are legal, decent, honest, and truthful. It covers all forms of marketing communications, including digital and social media, and applies to the entire marketing ecosystem. The standard is developed and adopted by ICC members to set a level for fair and honest competition, is applied by ethical companies worldwide and is referenced by many national marketing courts.

Standards and methodologies supporting verifiability

Standards are foundational to the credibility of sustainability claims. They provide common terminology, define scopes of assessment, and establish requirements for data quality, verification, and reporting. Adherence to standardized methodologies ensures comparability, reproducibility, and auditability of claims.

ISO 22095:2020 Chain of custody. General terminology and models outlines general terminology and models for chain of custody (CoC), which defines how material inputs can be tracked across a supply chain. It commonly refers to three models, such as 1) Controlled blending to ensure a fixed proportion of certified and non-certified inputs are blended with full documentation; 2) Mass balance to allow input variability over time while maintaining a certified average mix and 3) Book and claim to decouple the physical product from sustainability attributes, tracked via registry systems. Each method requires different levels of transparency and verification. For example, mass balance requires audit trails over defined physical mass flows into and out from a specified system boundary over defined time periods, while book and claim demands a robust digital registry on how claims about registered physical mass inflows relate to outflows into and out from a bookkeeping system over a specified averaging time frame.

The *ISO 14020 family of standards* provides the most recognized foundation for communicating environmental aspects and environmental impacts of products through environmental claims. For example, ISO 14021:2017 Environmental labels and declarations - Self-declared environmental claims (Type II environmental labelling) focuses on self-declared claims like "recyclable". ISO 14024:2018 Environmental labels and declarations - Type I environmental labelling - Principles and procedures addresses third-party ecolabels such as the Nordic Swan or EU Flower. ISO 14025:2010 Environmental labels and declarations - Type III environmental declarations - Principles and procedures formalizes Environmental Product Declarations (EPDs), which are LCA-based and independently verified. Additional supporting standards include *ISO/TS 17033:2019 Ethical claims and supporting information -- Principles and requirements* on ethical claims and *ISO 14067:2018 Greenhouse gases -- Carbon footprint of products -- Requirements and guidelines for quantification* on carbon footprinting. Together, these ensure claims are clear, non-misleading, and substantiated by methodologically sound assessments.

Life Cycle Assessment (LCA methods) according to ISO 14040:2006 Environmental management - Life cycle assessment - Principles and framework and ISO 14044:2006 Environmental management - Life cycle assessment - Requirements and guidelines are also specified in the standards related to *carbon footprint calculations* (ISO 14067:2018 Greenhouse gases -- Carbon footprint of products -- Requirements and guidelines for quantification), *environmental declarations* (ISO 14025:2010 Environmental labels and declarations - Type III environmental declarations - Principles and procedures) and *circular economy metrics* (ISO 59020:2024 Circular economy Measuring and assessing circularity performance). Because LCA often uses secondary data and is based on complex modeling assumptions, the accuracy and uncertainty of inputs must be reported clearly.

Circular economy performance is increasingly central to EU policy. The *ISO 59000 series on circular economy* (notably ISO 59004:2024 Circular economy Vocabulary, principles and guidance for implementation, 59010: 2024 Circular economy Guidance on the transition of business models and value networks, and 59020:2024 Circular economy Measuring and assessing circularity performance) offers guidance on implementing and assessing circularity. Claims like “fully recyclable” or “circular product” must adhere to these standards to be credible. *Net zero standards* for climate neutrality, *ISO 14068-1:2023 Climate change management Transition to net zero Part 1: Carbon neutrality* and *IWA 42:2022 Net zero guidelines* define net zero transitions, prioritizing emissions reductions before offsetting. These support valid net zero claims in line with international best practices.

Several standards on verification and validation, such as *ISO/IEC 17029:2019 Conformity Assessment - General principles and requirements for validation and verification bodies* provides general principles for validation and verification bodies and *ISO 14065:2021 General principles and requirements for bodies validating and verifying environmental information* sets competence requirements for these bodies, while *ISO 14066:2023 Environmental information Competence requirements for teams validating and verifying environmental information* provides details on personnel requirements. These are crucial to the reliability of third-party verified claims, including those based on LCA, chain of custody, and corporate ESG reporting.

Principles and methodology for forming verifiable claims and for verifying claims

Principles for verifiable claims

Sustainability claims must adhere to core principles outlined in ISO 14020:2022 and related standards. A verifiable sustainability claim is one that:

- demonstrate correctness,[1]
- is fact-based, and
- is verifiable[2], or is supplied with a certificate. [3]

The standard ISO/IEC 17029:2019 defines *verification* as confirmation of a claim, through the provision of objective evidence, that *specified requirements have been fulfilled*. The same standard defines *validation* as confirmation of a claim, through the provision of objective evidence, that the *requirements for a specific intended future use or application have been fulfilled*. These concepts are distinct but complementary in forming credible sustainability statements.
Common problems with claims include:

- Vagueness: Use of undefined terms like “sustainable”, “green”, or “eco”
- Misleading assertions: Claims that suggest compliance or superiority without a substantiated comparison
- Irrelevance: Statements highlighting traits that are mandatory or commonplace
- Aspirational claims: Promises of future performance without verified plans or baselines

These pitfalls are avoidable through structured claim formation, clear referencing to standards, and transparent communication of data and methods.

Methodology for forming verifiable claims and for verifying claims

The international standard ISO 14033:2019 Quantitative environmental information – Guidelines and examples was developed to provide guidance for the systematic acquisition and review of quantitative environmental information and data, to support decision making, aimed particularly at comparing quantitative environmental information. A simplified version of the framework of ISO 14033 is illustrated in Figure 2 (Carlson and Pålsson, 2000, 2001). Relating to the numbers inside the figure, the three phases 0-2 relate to metrology, phases 2-4 relate to systems analysis (phase 2 is shared between metrology and systems analysis), and phase 5 is the resulting claim.

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[1]correctness: correspondence with the universe of discourse (4.24), ISO 19157:2013, 4.5

[2]verifiable: can be checked for correctness by a person or tool, ISO/IEC/IEEE 15289:2019, 3.1.29

[3]A certificate ensures that even if the detailed underlying data cannot be disclosed, the scope and method of the verification is made available together with a verification of how the credibility of the verifying team or organization is ensured.

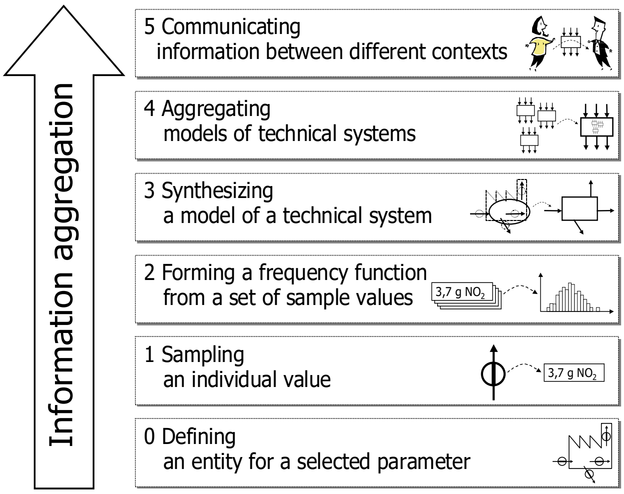

Figure. 2. Simplified representation of the framework of the ISO 14033 – Quantitative environmental information (Carlson and Pålsson, 2000, 2001).

From a verifiability point of view, the model in Figure 2 is interpreted in the following way: If a claim is constructed from phase 0 to phase 5 using specified methods within each phase and communicating transparently to the next phase, the resulting claim would be verifiable. Verifiability is checked from phase 5 and stepwise downwards through each phase, verifying all intermediate data and data manipulations down to the measurement of the primary data at phase 0. The opposite is also valid; if any phase is non-transparent, the claim is not verifiable. Hence, to make verifiable claims, one must ensure that all data sources and all data manipulations are made available to the verifier.

For simple claims based on a few measurement points, this is straightforward. But when claims are based on more advanced methods, such as LCA or mass balance calculations, verifications are generally made per information module (ISO 14025:2006) or other data cluster, such as verified data describing a total production plant, an organized set of transport routes or biological decay under different parametrized circumstances.

In practice, most claims are produced from secondary data, such as publicly available reports or databases and other literature, combined with modelling, assumptions and methodological rules. Such claims are often hard to verify by non-professional individuals and need to be verified by specific experts and accredited verifiers on the basis of the claims' specific methodological correctness. This relates not only to a lack of data but also to when data are proprietary, such as often is the case when shared across value networks.

With reference to the vertical structure of the framework ISO 14033 standard, a claim is seldom produced solely from performing measurements or collecting and calculating data from bottom up. For any analysis and calculation to produce a claim that meets its final quality expectations and requirements, the requirements on basic data, scope of modelling and the appropriate calculations need to first be specified. From such a specification one can conclude which data to acquire, imply the requirements for the appropriate measurement method, and interpret which statistical analysis and other data preparations are the correct ones in order to calculate and compile a certain claim.

Table 1 is a tool based on ISO 14033. It can be used both to ensure that the correctness of a claim can be verified and, if so, how to verify the claim. In the left column are the explanations of what is to be expected for that phase to be both understandable and meaningful. In the right column, the evidence that the claim is verifiable shall be provided. If a verifier can both access the evidence and understand it, that phase of the claim can be verified. As the verifier stepwise traverses through the table from top to bottom, a consecutive build-up of a full understanding of the verifiability of the claim is reached. If at each and every phase, evidence is accessible and understandable, the claim can be said to be true, false, or sufficiently significant.

Table 1. Top-down procedural structure for verifying the correctness of a claim

Verification of statement	
Aspect	**Substantiation verification**
The claim	
Start Requirements of objective (For what purpose is the information intended to be used by the end user?) The needs and the requirements of the objective or the target audience should be understood, in terms of which method is needed to measure the system performance, which temporal, technological, organisational, geographical, demographical and/or other sustainability scope to represent, as well as which data quality requirements to meet, such as age and uncertainty of data, which data sources to accept,	
End Meeting objective (Is the information applicable for the end user's intended use?) If correctly having considered the requirements of the objective consecutively during each step of the plan stage, the acquired data should be within the range of time precision and validity, as well as of any other quality aspect needed for the stepwise aggregation, through statistical analysis, coherent subsystem aggregation, final whole system aggregation, and eventual reporting or claim handed to meet the objective or communicate with the target audience. This shall be checked from bottom to top at each step before deciding whether the objective is met and, hence, whether the reporting or claim can be made.	Statements of verification process
6.3.5 Aggregate whole system This is where the data analyses are formulated into a quantitative statement of the total studied system. The whole system is aggregated according to the objectives, as described in 6.2.1. The system components are aggregated according to the appropriate aggregation type implied by the requirements of the objective. If there are deviations from Plan, such as lacking data on system components, the significance is estimated and corresponding measures are taken. Examples of corresponding measures could be to accept the lack or to make a rough estimate, both associated with an uncertainty measure. Depending on the magnitude of the significance, corresponding measures might not be sufficient. Instead, Plan may be corrected according to factual elements.	
6.3.4 Synthesize system components This is the step where the data analyses are formulated into quantitative statements about the subsystems of the total studied system. NOTE In this document, the term “synthesize” refers to combining all sub-systems so that they together constitute the whole system according to the requirements of the objective. System components are synthesized according to Plan, described in 6.2.2. To synthesize the system components, the parameters consolidated as described in 6.3.3 are related to the parameters of each system component, as described in 6.2.2. The parameters selected according to 6.2.3 that have different origins might not have a defined relationship with each other. The synthesis aims at defining this relationship to coherently describe the resulting system component. The relationships between the parameters can be established on the basis of mechanistic or other physical or chemical relationships, synchronization of timelines, logic or other relevant causalities. If there are deviations from Plan, such as a lack of data on system components, the significance is estimated and corresponding measures are taken. Examples of corresponding measures could be to accept the lack or to make a rough estimate, both associated with an uncertainty measure.	
6.3.3 Consolidate parameters Parameters are consolidated according to Plan, as described in 6.2.3. If data processing differs from Plan, the deviation is explained together with an estimation, evaluation or analysis of its significance. Significances are estimated iteratively, starting with a qualitative analysis that subsequently can lead to a thorough statistical analysis of uncertainty. From an industrial digitalization point of view, this is where “big data” statistical analysis, data filtering and other data science methods and tools enter environmental	
6.3.2 Acquire basic data Basic data are acquired according to the measurement method as described in 6.2.5. Failures and disturbances of measurements affect the quality of the acquired data. Estimations of the magnitude of significance of these failures and disturbances should be expressed in terms of ranges or distributions of uncertainty of the acquired basic data. From an industrial digitalization point of view, this step is where the sensor systems acquire data from the sensors and store it in databases.	
6.3.1 Set up measuring methods Setting up a measuring method means to implement what has been planned in 6.2.5. Sometimes the necessary measurement equipment and routines are already in place and only need to be identified. In some cases, adaptation of existing measuring systems might need to be carried out. From an industrial digitalization point of view, this step is where sensors and sensor systems are connected. The significance of any deviation of Plan should be estimated and, if needed, corrective values should be used or corrective routines established.	

Summarizing the support given by the framework of the ISO 14033 standard and the requirements proposed both by the Green Claims Directive and the ICC Framework for Responsible Marketing Communication, a five-step process may be formed to recommend how to form and formulate sustainability claims:

1. *Define purpose and audience.* Determine whether the claim aims to inform regulatory compliance, procurement decisions, or marketing messages. Adjust technical detail accordingly.
2. *Select terminology based on standards.* Use accepted definitions (e.g., ISO 14021 for "recyclable" or ISO 14067 for "carbon neutral"). Avoid jargon or generalized terms.
3. *Specify methodological parameters.* Outline system boundaries, temporal and spatial scope, and performance metrics. If possible, use formal standard methodologies (e.g., carbon footprint) or transparently describe boundaries and other limitations of the method used.
4. *Specify data sources and quality.* Report on which primary and secondary data were used and provide uncertainty ranges.
5. *Apply certification or third-party verification.* Where proprietary data cannot be disclosed, certification of data clusters, such as environmental product declarations' (ISO 14025) information modules, by qualified bodies (e.g., ISO/IEC 17029 accredited for the specific method addressed) can stand in as evidence.

Case examples: challenges in industry practice

In the research project on which this paper is based, a number of examples of real questionable green claims were identified. The examples included a broad width of statement types, ranging from presence of toxic substances and life cycle assessment, certified traceability and mass balance, from levels of vagueness to very specific but incorrect references to certificates. With the basis of those examples, the research project participants discussed reasons, backgrounds, challenges and alternatives to the different ways that formulations were made. The result of these exercises provided experiences resulting in the guidance provided in the following.

Case A: "Green Source". This claim is associated with the ISCC PLUS certification but fails to specify whether it refers to bio-based or recycled content, nor the percentage of certified input (The International Sustainability & Carbon Certification, n.d.). Therefore, the term "green" remained ambiguous and unverifiable. Guidance: Specify the percentage of certified input, type of certification (e.g., mass balance or book and claim), and sustainability scope (e.g., GHG reduction, deforestation avoidance).

Case B: "Less Climate Impact". This comparative claim lacks a defined baseline. While it refers to the use of bio-based inputs, it was not presented together with a reference to a verified carbon footprint study or lifecycle boundary specification. Guidance: Comparative claims must clearly indicate: 1) what they are compared to, 2) which parameters are compared, and 3) how results were measured or modeled.

Case C: "Fossil-Free Product". The claim refers to a bio-attributed product according to a non-disclosed mass-balance calculation, excluding whether or not fossil energy is used in the transport and manufacturing stages. ISO 14021 states that "free-from" claims must indicate background levels. Guidance: Reserve "fossil-free" for cases where fossil resources are not used in any upstream or downstream processes, and when such is explicitly defined in the scope or in its exceptions.

Case D: "Environmentally Friendly". A generic claim applied across multiple product types with no specific environmental impact areas mentioned. It creates a false impression of comprehensive sustainability benefits. Guidance: Replace with claims that are function-specific and supported by third-party standards, such as "70% lower GHG emissions during use phase based on an ISO 14067 compliant carbon footprint study (which should also be referenced and made available)".

These cases illustrate a broader lesson: without referencing standards, defining scope, or supplying supporting data, even well-intentioned claims become legally and ethically questionable.

Business-to-business (B2B) implications

Although the proposed Green Claims Directive and the ICC Framework for Responsible Marketing Communication primarily address business-to-consumer (B2C), their principles inevitably extend to B2B interactions. In sectors such as manufacturing, construction, and chemicals, sustainability-related information is increasingly embedded in procurement processes, supplier evaluations, and regulatory reporting. Companies along the value chain must share accurate, verifiable data to support partners in meeting their own compliance and disclosure obligations.

The implementation of the Digital Product Passport (DPP), as outlined in the Ecodesign for Sustainable Products Regulation (ESPR), exemplifies this trend. The DPP will require the continuous sharing of sustainability-related data between all value chain stakeholders, such as producers, distributors, consumers, recyclers, and regulators. This reinforces the need for consistency and verifiability, not only to comply with law and business ethics, but also to maintain operational efficiency and trust in business relationships.

Further, financial stakeholders increasingly demand substantiated ESG disclosures for risk assessments, sustainable finance eligibility, and corporate ratings. Verifiable claims help fulfill requirements from instruments like the EU Taxonomy and Sustainable Finance Disclosure Regulation (SFDR). As such, internal sustainability claims used in ESG reporting may face scrutiny equal to, or greater than, public-facing marketing claims.

Conclusion

As sustainability becomes a mainstream determinant of market value, trust in sustainability claims is both a regulatory imperative and a business strategic asset. The European Green Deal and its associated directives signal a clear shift toward mandatory substantiation and verification of all sustainability-related statements.

This paper has outlined the regulatory landscape, relevant standards, and best practices for ensuring claim verifiability. It also highlights pitfalls from real industry cases and proposes a structured method for claim formulation. While compliance may be resource-intensive, especially for SMEs, the long-term benefits include reduced legal risk, improved stakeholder trust, and better alignment with sustainable finance mechanisms.

Ultimately, fostering a credible information environment will allow sustainable choices to drive real transformation. Verifiable claims are not merely regulatory obligations; they are essential instruments for trade ethics and brand management and guide systemic change toward climate neutrality and circularity in the European economy.

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Sustainable Innovation: An Overview

Martin Charter
Director
The Centre for Sustainable Design
University for the Creative Arts
United Kingdom

Trevor Davis
Managing Director
Trevor Davis Associates
United Kingdom

Introduction

The paper provides an overview of key topics and landmarks that have emerged over the last 25 years that relate to sustainable innovation. A number of framework changes are highlighted rather than discussion over specific innovations at a product level e.g. increasing energy efficient products or products designed for repairability, etc. The paper is not designed to be a comprehensive review and analysis of the last 25 years of the evolution of sustainable innovation but aims to highlight some of the key changes over the last two decades or so. There has been change. Despite the growing scientific evidence of the climate change imperative, there is a current slowing down and even reversing of sustainability and climate-related goals and initiatives driven from the political right and the fossil fuel lobby. However, Sustainable Development and climate change has arisen as global areas of concern with development of international and national policy and standards emerging in the 1990s and then the 2000s. 2015 was a landmark year with launch of the United Nations Sustainable Development Goals (SDGs), Paris Agreement, Science Based Targets initiative (SBTi) and the European Commission's (EC) Circular Economy Action Plan (CEAP). Growing concern over climate change and increased waste challenges led to the EC to set up the Green Deal and a 2nd CEAP in 2019-2020 to transition Europe to a lower carbon and circular futures. In 2024, as part of the 2nd CEAP, the EC passed a significant framework regulation to mainstream sustainability into products – Ecodesign for Sustainable Products Regulation (ESPR). International frameworks and standards on climate change are now being supplemented by international and national standardisation on circular economy (CE) with national CE strategies and action plans in place in over seventy countries as identified by Chatham House. The next challenge is growing concerns over business impact on biodiversity and nature-based solutions, and regenerative design is emerging area of discussion. The accelerated pace of change in policy and standards development is an increasing challenge for business. The paper concludes with discussion over future issues for design and development, these include aligning business, government, and academia; design practice changes; embedding product decarbonisation; materials development; data, AI, and design challenges; and transitioning the workforce.

Sustainable Development

Over the past 25 years, sustainability has transitioned from an emerging issue to a central global priority, driven by mounting concerns over climate change, resource scarcity, and environmental degradation. The Earth Summit in 1992 effectively launched the sustainable development agenda - building on the Brundtland Commission report published in 1987 - but did not discuss climate change, circular economy, or biodiversity. It took almost 25 years to codify the diverse aspects of the agenda. The United Nations Sustainable Development Goals (SDGs) were launched in 2015 and provided the first comprehensive framework for addressing global challenges such as poverty, inequality, climate change, and environmental degradation. These seventeen interconnected goals and 169 objectives aimed to create a more sustainable, equitable, and prosperous world by 2030.

The SDGs are high level but SDG 12 - Responsible Consumption and Production – is particularly relevant for sustainable innovation as it emphasises the need to balance sustainable consumption with sustainable production practices. While many organisations have made progress designing out waste, and developing products that can be reused, refurbished, or recycled, fostering a shift away from over consumption is proving more difficult. Changing or shifting consumption in a more sustainable direction is key element of creating the markets for sustainable products and services.

This goal is directly aligned with the principles of ecodesign, circular economy, and sustainable resource management. Product designers are encouraged to reduce waste and energy throughout the lifecycle, increase resource efficiency, and minimise environmental impacts through sustainable material selection, repairability, and recyclability. However, it is unclear how many of those involved in design and development are aware of the SDGs and have tried to apply them at a product level as they are very generic.

As we approach this deadline of 2030, progress on the SDGs has been uneven, with many challenges remaining, particularly in addressing climate change, biodiversity loss, and social inequality.

Climate Change

The first United Nations Climate Change Conference (COP1) was held in Berlin in 1995, setting the stage for decades of international climate negotiations aimed at mitigating global warming. Major milestones include the Kyoto Protocol of 1997, which set binding emission reduction targets for developed countries, and the landmark Paris Agreement in 2015, where nearly every nation committed to limiting global temperature rise to well below 2°C, with efforts to cap it at 1.5°C to prevent catastrophic climate impacts.

The Greenhouse Gas (GHG) Protocol was established in 1998 as a standardised global framework for measuring and managing greenhouse gas emissions. The GHG Protocol has become the most widely used standard for tracking emissions. More recently, there has been a stronger focus on reducing Scope 3 emissions, which are the indirect emissions that occur throughout a company's supply chain, including those generated during outsourced production. Reducing Scope 3 emissions has driven deeper collaboration across supply chains, with a focus on improving data transparency regarding material sourcing, production processes, and product lifecycle impacts. This requires companies to adopt low-carbon materials, more energy-efficient processes, and innovative technologies that reduce emissions during production, use, and disposal phases, lowering the overall carbon footprint of products and services.

In 2015, the Science Based Targets initiative (SBTi) was launched to mobilise the private sector in taking urgent climate action by setting emissions reduction targets aligned with the latest climate science. For some companies, SBTI plays a significant role in product development by providing a framework that aligns product emissions reduction strategies with global climate targets.

Over the past two decades, renewable energy technologies such as solar and wind power have experienced significant cost reductions, accelerated by widespread adoption. This in turn has influenced innovation at the product and service level. These advancements have not only transformed energy infrastructure but also sparked new opportunities in product design and development, particularly in integrating renewable energy technologies into everyday products and services. China, for example, has heavily invested in renewable energy and is a global leader in the design and manufacturing of electric vehicles (EVs), which incorporate innovative technologies to reduce emissions and improve energy efficiency.

Growing concern over waste and emergence of Circular Economy

Since the nineties, there has been a growing focus on reducing waste and reusing materials. For example, the EC Waste Framework Directive (2008, updated 2018) is an example of government action to set targets for recycling and reuse, emphasising resource efficiency and waste prevention in product design, promoting the use of secondary materials. The environmental impact of single-use plastics has come under the microscope over the last 10 years and has led to widespread legislation and innovation in packaging. The EC Single-Use Plastics Directive (2019) bans certain single-use plastic products such as straws, cutlery, and plates and sets targets for reducing plastic waste and increasing recycling rates. It also requires member states to introduce measures that encourage alternatives and reduce consumption. Companies across industries are increasingly adopting biodegradable, compostable, and reusable packaging materials, while major corporations, including Unilever and Nestlé, have pledged to make all packaging recyclable or reusable by 2025. Recent innovations in green chemistry and bio-based materials, such as plant-based plastics, have emerged as key alternatives to traditional, fossil-fuel-based materials. Companies like LEGO and Danone are exploring bio-based options to reduce their reliance on petrochemicals.

Globally, a growing number of governments are setting the stage for increasing policy development related the Circular Economy. In 2024, Chatham House identified, seventy-five national circular economy "calls to action, roadmaps, and operational strategies" of various quality and actionability. This shift reflects a growing recognition that the traditional linear economy (take-make-waste) is unsustainable and that new models are required to close material loops, reduce waste, and lower environmental impact. Governments are driving this transition through policies that encourage resource efficiency, reduce waste, and promote product durability and recyclability.

During the 2010s, businesses started to re-think their approach to product end-of-life and waste and began adopting circular economy principles. Companies like Patagonia, Philips, H&M, and IKEA have been pioneers in product longevity, recycling, and reuse initiatives, launching take-back programmes and products designed for repairability and recyclability. However, this movement highlighted that business alone could not make the shifts needed to make the circular economy a reality, as most waste management systems are geared to a take-make-waste linear economy. A systems perspective is needed.

European Green Deal, Circular Economy Action Plan (CEAP), and Ecodesign for Sustainable Products Regulation (ESPR)

In 2019, the EC's Green Deal emerged as a proactive example of government regulation to drive sustainability in Europe. The Green Deal sets ambitious targets for net zero emissions by 2050 and a 55% reduction by 2030 and encompasses a wide range of sectors from energy to agriculture. The legislation integrates policies designed to drive sustainable growth, circular economy practices, and biodiversity protection. The Green Deal is supported by the Circular Economy Action Plan (CEAP). The CEAP was introduced in 2015 by the EC and updated in March 2020 and is designed to accelerate Europe's transition toward a circular economy. It emphasises sustainable product design, waste reduction, and resource efficiency across multiple industries. The CEAP shows the direction of travel for Europe and in 2024 the EC announced the development of Circular Economy Act as a political priority. The intent is to create market demand for secondary materials and a single market for waste.

These European regulatory frameworks, combined with evolving standards like ISO 59000 and new developments such as the EC Ecodesign for Sustainable Products Regulation (ESPR), are laying the groundwork for a global transition to circular product and service models. Their impact is not limited to Europe as supply chains in most industries are global, and the frameworks and standards provide a role model for others to follow. ESPR forms the foundation of the EC's strategy for promoting environmentally sustainable and circular products. As well as bringing ecodesign requirements to new sectors, this legislation brings new circularity considerations into force.

Circular economy and standardisation

A key aspect of this transition is the development of international standards that provide frameworks for circular economy practices. ISO TC 323 was established as a technical committee to develop international standards for the circular economy in 2019. Its goal is to create a global consensus on definitions, principles, and frameworks that support businesses in implementing circular practices, ensuring consistency and comparability across industries and regions. The first series of standards were published in 2024 and are now moving into revision to be completed in 2028.

The introduction of the ISO 59000 family of standards marks a significant step towards establishing a comprehensive framework for the circular economy. These standards are designed to guide organisations in the implementation of circularity at an organisational and management level. The first standards, published in 2024, include ISO 59004 (key terminology and principles), ISO 59010 (Circular economy Guidance on the transition of business models and value networks) and ISO 59020 (Circular economy Measuring and assessing circularity performance). In addition, ISO TC 323 have published including 59040 (Circular economy – Product circularity data sheet) which addresses business-to-business data exchange and ISO 59014 (Environmental management and circular economy Sustainability and traceability of the recovery of secondary materials).

While these recently published standards set a high-level framework, there is recognition that they are still in the early stages of development and adoption. As result as mentioned above, ISO 59004, ISO 59010 and ISO 59020 will move into a revision process in 2025. Other standards are in the process of development or proposal stage in ISO TC 323 include Extended Producer Responsibility (EPR), Digital Product Passports (DPP), Circular Economy Management Systems and Circular Design.

In Europe, CEN TC 473 was established in 2023 to create standards for Europe on circular economy – effectively acting as a European mirror committee to ISO TC 323. However, product circularity standardisation started in the 2010s. Under the EC CEAP in 2015, the EC mandated CEN to develop a series of standards related to *materials efficiency* - effectively product circularity – to address aspects such as durability, repairability, and recyclability of products. These standards were initially targeted at the energy-related products that fell under the EC Ecodesign Directive. However, now with the launch of EC ESPR the product scope has been broadened. Additionally, a CEN standard on circular design (EN 45560) was published in November 2024 and there is now discussion over this being used as a base for an ISO standard.

Industry standards and certification schemes such as the Cradle to Cradle Certified® Product Standard – focused on a product rather than a process level e.g. design and development - have also become part of the standards landscape. However, by their very nature, these “self-certification” schemes may be less rigorous than those associated with national or international standards bodies that are not based on consensus of international experts.

However, as mentioned we are still in the early days of the development of these circular economy standards. It is too early to judge their impact, and the development of these standards is evolving to broaden from an initial set of priority sectors (such as electronics) to cover all products and sectors. This is only the beginning of what is a 20-year process to fully integrate circular economy principles into organisations and circular design principles in design and development processes across industries.

Nature, biodiversity, and regeneration

Protecting nature and biodiversity is the latest global priority. Policy makers now recognise the importance of ensuring the health of ecosystems that provide vital services such as clean air, water, food, and climate regulation. Biodiversity underpins the resilience of ecosystems, enabling them to adapt to environmental changes and disturbances. Deforestation, pollution, and over-exploitation of resources are rapidly degrading ecosystems and endangering future well-being. Product and service design, development and commercialisation have a key role to play. For instance, a shift toward biomaterials and regenerative design at the product level brings both exciting opportunities and significant challenges. In the past, biomaterials were largely limited to natural fibres, such as cotton, hemp, and bamboo, which offered more sustainable alternatives to synthetic materials but often came with performance limitations. Today, innovations in biomaterials are pushing the boundaries, with developments in bioplastics, mushroom-based materials, and algae-derived polymers that offer viable, eco-friendly replacements for traditional materials like fossil-fuel based plastics. However, the challenge remains in scaling these materials for mass production while ensuring their durability, cost-effectiveness, and overall environmental impact compete with traditional materials.

The word “regenerative” entered the sustainability vocabulary in 1990s from the world of building design and development. In the 2010s, the term has gained momentum in many fields, most notably in agriculture, but due to the increasing usage and lack of formal definition there are increasingly instances of greenwashing occurring. Regenerative design at a product level goes beyond sustainability by seeking to regenerate resources rather than conserve them. Examples of regenerative product design include self-healing materials, which can repair damage autonomously, extending the product's lifecycle and reducing waste. Biodegradable packaging made from seaweed or mycelium that can decompose naturally but also enrich soil health if integrated into compost systems. However, these innovations face challenges such as ensuring consistent performance, integrating regenerative materials into existing supply chains, and overcoming consumer scepticism about the longevity and functionality of such products.

Looking toward the future, regenerative business models and product design will likely evolve to include circular supply chains that focus on constant material renewal, closed-loop systems that integrate product return and re-manufacturing, and products that actively enhance ecosystems, like carbon-sequestering building materials or air-purifying fabrics. Regenerative design is being discussed at a conceptual, systems level, with product-level applications still in their infancy. The challenge moving forward will be to make these regenerative products commercially viable, scalable, and able to integrate into broader business strategies that prioritise the regeneration of ecosystems, resources, and even economic value.

Frameworks and methodologies

The Triple Bottom Line (TBL) – balancing environmental, social, and financial aspects - provided one of the first frameworks to help company leaders to balance revenue generation with the associated ecological footprint and contribution to societal well-being. However, TBL is a conceptual framework and focused on overall company approaches rather than being *product specific.*

New ways to think about product and service sustainability appeared in the 1990s. Ecodesign – the integration of environmental consideration into design and development with a view of reducing environmental impacts - has become one of the most widely adopted terms in Europe, but different terms are still used around the world to convey the same idea. For example, green design in China, environmentally conscious design in Japan and 'Design for Environment' in the US. The terms "design for sustainability" and "sustainable design" – emerged in the 1990s - has been limited primarily to academic discussion e.g. the integration of social, alongside environmental, and financial consideration – from a TBL perspective – has had limited take-up in design and development.

Despite ecodesign discussions emerging in the 1990s, the first significant policy initiative emerged in Europe in 2009. The EC Directive for Ecodesign was launched in 2009 with specific focus on reducing energy consumption and CO2e from energy-related products. Fifteen years on in 2024, the EC launched a framework directive - the Ecodesign for Sustainable Products Regulation (ESPR) - that significantly broadens the product design requirements and information for almost all categories of physical goods that come onto the EU market.

Ecodesign standards have also emerged. For example, the ISO 14000 family for environmental management systems (first introduced in 1996) now has a sister standard - ISO14006:2020 (published in 2020) - that links ecodesign to environmental management and quality management systems. In parallel, IEC 62430:2019 was published in 2019 to provide guidance on how to integrate environmental considerations into design and development processes. The standard is a dual logo between IEC and ISO, providing guidance to cover all products across all sectors broadening from initial version of the standard that was focused on electrical and electronic equipment.

Life Cycle Assessment (LCA) emerged a methodology to assess the environmental impacts of a product or service throughout its entire lifecycle in the 1990s. This provided designers will a tool to consider the full environmental footprint of their designs and identify opportunities for improvement. Since then, hundreds of checklists and tools have been produced to cover ecodesign and lifecycle considerations. However, many of these are not applied in industry as they do not take account of actual decision-making requirements. Cradle-to-cradle design was also introduced by William McDonough and Michael Braungart in the late 1990s. This framework advocates for designing products with the intention that all materials used can be reused or safely returned to nature at the end of their lifecycle. The cradle-to-cradle approach focuses on eliminating waste and was an early example of thinking about circular systems where materials are continuously cycled. New tools and processes will be required to help designers think through what biodiversity and regeneration means at a product level, as well as at a systems level.

During the 1990s, eco-certifications were also launched. Labels like Fairtrade, Energy Star, and Forest Stewardship Council (FSC) became widely adopted, setting industry standards for ethical and sustainable sourcing, energy efficiency, and responsible forestry. These certifications have helped consumers make more informed decisions and pressured companies to improve their product designs and supply chains. However, false product and service sustainability claims in annual reports, advertising and on packaging have also become more common. EU legislation in 2024 is one response to tackling misleading claims about environmental benefits ("greenwashing").

The Future

While the new policy and standards developments are to be applauded, the speed of change has become a significant challenge for companies. Governments worldwide are rapidly introducing new regulations and updating existing ones to meet environmental goals, such as decarbonisation and waste reduction. This swift pace of change places immense pressure on businesses to continuously monitor and respond to evolving policy landscapes. Companies are finding it increasingly difficult to stay ahead of these developments, especially as policies like the ESPR and new circular economy standards broaden their scope across sectors and products.

Many organisations struggle to track the evolving regulatory and standards landscape, facing the risk of non-compliance or missed opportunities for innovation. The sheer volume and complexity of policy changes, whether it is new emissions reduction targets, new EPR schemes, or new circular design requirements, mean that companies need dedicated people and resources to track these developments and rapidly adjust their strategies. Failing to do so can lead to regulatory penalties, product re-design, or reputational damage. In today's fast-moving regulatory environment, businesses must invest in proactive monitoring systems, engage with policymakers early, and be flexible enough to pivot their products and services to remain compliant and competitive.

Looking ahead, the next phase of sustainability will require bold and coordinated action specifically focused on products, new materials, services, and business models. The technological, regulatory, and economic changes initiated by frameworks like the Paris Agreement and the EU Green Deal must be scaled up across all industries, transforming the way products are designed, developed, and delivered. For example, since ESPR has a broad product scope it will send ripple-effects through global supply chains in almost all product sectors. Electrification of transport will drive innovation in electric vehicles, batteries, and supporting infrastructure, while energy system decarbonisation will reshape product categories such as appliances, industrial equipment, and home energy systems to be more energy-efficient and powered by renewables. Advances in carbon capture and storage (CCS) will also necessitate new products and materials designed to integrate CCS technologies across various sectors.

Those involved in design and development will have to tackle a new series of sustainability challenges over the next 25 years. These include:

Aligning business, government, and academia

Sustainable innovation involves many stakeholders. Each stakeholder group has distinct drivers: governments focus on regulation and policy enforcement; businesses on innovation and profitability; academia on research and knowledge creation; and civil society on advocacy and accountability. Aligning these varied drivers will be critical, but internal challenges, such as balancing short-term economic pressures with long-term sustainability goals, overcoming resource limitations, and managing competing priorities, will complicate this process for those involved in product design and development. Tougher product-related environmental policies seem inevitable, hence stakeholder alignment presents significant challenges for design and development of products, as each sector has differing priorities and timelines. Businesses, government bodies, and academic institutions must collaborate to create a cohesive strategy that promotes sustainable innovation while balancing regulatory, commercial, and research-driven goals. Designers will need to monitor closely evolving regulatory frameworks that encourage green practices and penalise unsustainable ones (e.g., overproduction and overconsumption). This necessitates strong collaboration between all three sectors to ensure regulatory compliance does not stifle innovation. The need to change consumer behaviour to reduce overconsumption and encourage more sustainable lifestyles, can only be addressed by governments working with both academia and businesses to shape new policies and rethink traditional growth models to prioritise long-term sustainability over short-term economic gains.

Design practice changes

In the future, product designers will face a range of practical challenges as they work to meet the growing demand for sustainability. One significant issue will be navigating the increasingly stringent requirements set by regulations and standards. For example, new laws like ESPR will require products to meet stricter criteria for durability, repairability, and recyclability. This means that designers will have to consider the full lifecycle of a product, from the sourcing of materials to end-of-life disposal and ensure compliance with evolving rules that can vary across markets. Meeting these requirements will also come with cost pressures, as sustainable materials and processes often carry higher initial costs. Designers will need to balance the expense of using eco-friendly materials, such as biodegradable plastics or bio-based composites, against the economic realities of production budgets.

There will also be growing pressure to innovate continuously, as companies compete to offer more sustainable products. For example, incorporating advanced materials that have lower environmental impacts, such as bio-based packaging or recycled carbon fibres, might be an ideal solution, but these materials may still be in development stages, have limited availability, or require new manufacturing techniques that add costs. On the technical side, designers will face challenges in integrating new materials and sustainable practices into existing production processes. For instance, a product made from recyclable materials might perform differently than one made from conventional materials, requiring adjustments to the design to maintain performance standards. Similarly, designing products for modularity or repairability can introduce complexities in assembly processes or require the use of fasteners and joints that complicate manufacturing. Balancing all these factors will require designers to navigate trade-offs carefully. For example, using a more sustainable material might reduce a product's carbon footprint but could increase costs or affect durability. Conversely, focusing solely on lowering costs might lead to choices that compromise the product's environmental performance. To avoid such trade-offs, designers will need to adopt a holistic approach, considering multiple sustainability dimensions simultaneously such as reducing energy use during production, minimising waste, and choosing materials with low environmental impact.

Embedding product decarbonisation

Designers and developers will need to create products that minimise emissions throughout their entire lifecycle, from sourcing materials to end-of-life disposal. This will require the integration of low-carbon technologies, energy-efficient production methods, and materials that are either reusable or recyclable at scale. In some industries, such as fashion, the design of virtual products may offer a route forward but there needs to be an improved understanding the lifecycle environmental impact of online solutions. Universities and other research organisations should spearhead research into new low-carbon materials.

Materials development

From the creative industries to heavy manufacturing, each sector will face unique challenges in using virgin and secondary materials. In the fashion industry, designers will increasingly need to explore and commercialise bio-based materials like mycelium and algae that offer eco-friendly alternatives while maintaining performance and aesthetic appeal. In heavy manufacturing, the focus will shift toward secondary materials, requiring much improved traceability and provenance. Universities and other research organisations will play a crucial role in further developing materials such as biodegradable plastics or self-healing materials, which could revolutionise industries from textiles to electronics.

Data, AI, and design challenges

Designers will need to master the use of product information and data. Product lifecycle data (tracking everything from material sourcing and carbon footprint to durability and recyclability) will play an increasing role in design and development decisions. Access to real-time data and digital product passports (DPP) will allow designers to make informed choices about materials and processes based on evidence. Academia should contribute to research to standardise how product lifecycle data is collected, reported, and shared across industries. By developing frameworks for data standardisation, universities working with other stakeholders can help ensure that the data used by designers is consistent, reliable, and comparable, regardless of where or how it is sourced.

Generative AI is set to play a transformative role in the practice of design, fundamentally changing how products and services are conceived and developed. It can simulate performance outcomes, optimise material use, and suggest eco-friendly alternatives, speeding up the design process while embedding sustainability principles from the start. This technology also enables mass customisation, allowing products to be tailored more precisely to individual needs, which helps reduce overproduction and waste.

However, to fully harness the potential of generative AI, designers must have access to appropriate tools, up-to-date knowledge, and educational resources that equip them to use AI effectively and ethically. Universities can lead in the research and development of AI tools and algorithms tailored specifically for sustainable product design, ensuring that AI-driven approaches do not lead to unintended consequences, such as increased material consumption or unsustainable production practices.

There is also a need to increase awareness of sustainability issues within the design community, so that AI tools are used with a clear understanding of their environmental and ethical impacts. By advancing AI tools that prioritise sustainability, providing educational programmes on their use, and promoting ethical design practices, academia can help shape the future of AI integration in a way that supports responsible innovation and sustainable outcomes.

Transitioning the workforce

Over the next 25 years, the design and development workforce will face significant challenges as industries transition to more low carbon, circular and bio-based models. One of the most pressing challenges will be the need for reskilling and capacity building as the demand grows for designers and developers with expertise in product carbon footprinting, circular design principles, such as modularity, repairability, and material efficiency, as well as emerging biomaterials and other green technologies. As industries continue to adopt digital tools, designers will need to acquire new skills in data-driven design, leveraging real-time insights to improve product sustainability and lifecycle performance. Furthermore, cross-disciplinary collaboration will become crucial, requiring designers to work closely with engineers, sustainability experts, and technologists to integrate circular economy practices and cutting-edge innovations into product development. Through research and education, universities can ensure that designers are not only familiar with new techniques, processes and materials but also understand their application and potential impact.

End note

Over the next decade, designers and developers will need to continually adapt to new technologies, shifting consumer expectations, and changing regulatory landscapes linked to sustainability, climate change, circularity, and biodiversity. Multiple questions will need to be addressed including, for example, what new metrics and frameworks will be necessary beyond 2030 to measure progress effectively? What tools and methods are needed to better measure and manage the trade-offs between environmental, economic, and social aspects of sustainability in product design? What role will digital product passports (DPPs) and traceability systems play in improving supply chain transparency, and how can they be standardised across different industries? How can businesses foster a culture of sustainability in product development teams, ensuring that ecodesign principles are consistently prioritised across all projects? What policies and standards are required to ensure that data quality and availability do not become barriers to sustainable product development? What role will emerging technologies, such as AI and advanced materials such as nanomaterials and smart materials, play in driving product and service innovation? How can manufacturers scale production, and accelerate the adoption, of low-carbon materials and biomaterials? How can businesses and governments ensure that the economic incentives adapt to align with sustainability goals such as Net Zero targets? Speculating into the future, we may see also the emergence new economic models that fully integrate low carbon, circular economy and regenerative principles or regulatory frameworks that require comprehensive product lifecycle accountability. Only by addressing these challenges and uncertainties can the global community build a truly sustainable future for products and services.

Digital Decarbonisation in Fashion: A Case Study for Creative Industries' Climate Resilience

Emily Megan Cox

Doctoral Researcher

Loughborough University

United Kingdom

Abstract

The fashion industry exemplifies a critical challenge in the creative sector: balancing digital transformation with environmental sustainability. While digital technologies such as AI, virtual sampling, and predictive analytics offer improved efficiency and operational resilience, they also introduce significant and growing carbon costs. This paper introduces the concept of the digital sustainability paradox - the simultaneous pursuit of environmental goals through technologies that expand carbon footprints. Drawing on fashion as a case study, the paper critiques existing policy frameworks such as the UK's DBT supply chain resilience model, arguing it inadequately accounts for the environmental impacts of digital infrastructure. With the upcoming introduction of EU Digital Product Passports, digitalisation is no longer optional but mandatory, intensifying energy demands across fashion systems. The paper proposes a conceptual foundation for digital decarbonisation and advocates for the development of a new framework of digital climate resilience that aligns operational efficiency with environmental responsibility in creative industries.

Introduction

The creative industries face a complex challenge: how to harness digital technologies for efficiency and sustainability whilst managing their own expanding digital carbon footprint. Research on the adoption of new digital technology within this sector has largely focused on its potential, applications, and benefits, with little consideration given to the energy consumption of the digital infrastructure itself (Casciani et al., 2022). The fashion industry serves as an ideal case study for exploring this challenge within the creative sector; it operates at the intersection of environmental, cultural, and technological issues, and is rooted in the production of physical garments that everyone, everywhere, consumes (Brown & Vacca, 2022; Mesjar et al., 2023).

Not only this, but the fashion industry is responsible for approximately 10% of global carbon emissions and is the second largest industrial polluter and water consumer in the world (European Parliament, 2020); Simultaneously, the sector is becoming increasingly digitised and globalised at all stages of its system, spanning from fibre sourcing through to post-use waste management (Casciani et al., 2022). Climate disruption, regulatory pressure and evolving consumer expectations create a critical juncture for systemic transformation, illustrating a key tension: digitalisation both creates unprecedented opportunities and significant risks. This creates what this paper will refer to as the digital sustainability paradox: the simultaneous pursuit of environmental goals through technologies that expand carbon footprints. This paradox is particularly acute because while digital technologies can enhance system resilience to various operational and market shocks (Zhan & Li, 2024), they may simultaneously undermine resilience to climate change, the most critical long-term threat facing the industry.

Current policy frameworks reflect this disconnect between traditional resilience thinking and digital-environmental realities. Building resilience against climate change requires fundamentally different approaches, yet existing frameworks like the Department for Business and Trade's 5-pillar supply chain resilience model (diversification, international partnerships, stockpiling, onshoring, and demand management) inadvertently conflict with climate goals (Department for Business & Trade, 2022; NPSI et al., 2023). Stockpiling strategies, for instance, directly contradict environmental objectives through increased resource consumption, while the framework's general approach overlooks the specific demands of AI-driven systems and data infrastructure that now underpin modern industries.

The creative industries, some of the largest and most digital of the UK's industrial centres, are uniquely vulnerable to this paradox due to their rapid adoption of digital technologies (Jeary & Gajjar, 2024). Despite this, there is limited academic understanding of how digital decarbonisation strategies can resolve this paradox within the creative industries. This paper establishes a conceptual foundation for understanding and addressing the digital decarbonisation of the fashion system and advocates for the development of a fashion-specific framework for digital climate resilience.

The Current Fashion Landscape

The fashion industry operates as a complex network of interconnected value chain stages, each generating substantial environmental burdens that have been well-documented in existing literature. The European Environment Agency reports that textile purchases in the EU in 2020 generated approximately 270 kg of CO_2 emissions per person, with fabric production representing one of the most resource-intensive stages (European Parliament, 2020). Dyeing processes alone consume up to 200 litres of water per kilogram of fabric and contribute to 20% of global water pollution through untreated wastewater (European Parliament, 2020).

Existing sustainability research has extensively documented the industry's structural challenges: overproduction drives waste with an estimated 92 million tonnes of textile waste generated annually, while accelerated trend cycles have transformed fashion from two seasonal collections to 52 micro-seasons in fast fashion, fundamentally altering consumption patterns and production volumes (European Parliament, 2020; Shaikh & Rane, 2025).

Digital Infrastructure

While digital technologies are predominantly positioned as environmental solutions, promising reduced waste through better demand prediction, optimised supply chains, and increased resilience, they have simultaneously enabled the acceleration of production cycles that drive overconsumption. Over 70% of fashion companies now use AI tools for demand forecasting and personalised recommendations (Bain, 2022).Virtual sampling adoption has surged, with Macy's increasing usage from 5% (2019) to 61% (2022), reducing material waste and development time (Bain, 2022).

Tools such as AI-driven trend forecasting, automated manufacturing, and e-commerce platforms have amplified production efficiency while facilitating fast fashion business models that prioritise speed and scale over sustainability (Muthuswamy & M. Ali, 2023; Singh et al., 2024). This dual role of digital technologies as both potential solutions and drivers of environmental impact creates complex challenges that require deeper examination of their hidden carbon costs.

The Digital Decarbonisation Challenge in Fashion

The Hidden Carbon Footprint

The digitalisation of industries hides substantial energy costs within seemingly efficient processes. This narrative of digital technologies as a 'solution' obscures additional environmental burdens from the technologies themselves; the problem, however, is that digital technologies don't just reduce carbon impacts, they also have the potential to add to them (Hodgkinson et al., 2023).

Digital decarbonisation refers to the need for, and efforts of, systematic reduction of carbon emissions from digital technologies, data processes and infrastructure, with particular emphasis on minimising energy consumption and optimising the sustainability of emerging technologies like AI and cloud computing (Hodgkinson et al., 2023; Jackson, 2024; Jackson & Hodgkinson, 2022; Lockwood et al., 2023). This concept, whilst still largely in its nascent phases of development, has gained urgency as the hidden energy consumption of digital systems becomes increasingly apparent.

The ICT Sector is responsible for 2-3% of global GHG emissions, and this is largely due to the energy consumption required to run data centres and digital infrastructure (Freitag et al., 2021; International Energy Agency, 2022). This environmental impact creates a paradox when digitalisation seeks to reduce an industry's carbon footprint. As industries seek to digitise and digitalise, they simultaneously contribute to carbon emissions through the energy demands of data storage, processing and transmission (Dwivedi et al., 2022; Jackson & Hodgkinson, n.d.).

AI & Data Growth

Developing a single large-scale AI model can consume around 1287 MWh of electricity and release 284 tonnes of CO_2, comparable to the lifetime emissions of 5 cars (Hao, 2019; Strubell et al., 2019). AI's heavy reliance on large-scale datasets further exacerbates this problem, as data must be stored, processed, and transferred across networks, creating a cycle where increased data usage drives greater infrastructure needs, and subsequently higher environmental costs (Masanet et al., 2020).

Data Centres & Infrastructure Demands

Data centres consume over 200 TWh of electricity annually, accounting for approximately 1% of global energy use, and 2% of global GHG emissions (International Energy Agency, 2022). And, as digital technology use and AI become more ingrained in operations, this energy usage is expected to rise to 8% of global electricity by 2030 (International Energy Agency, 2022; Thangam et al., 2024). Extending beyond energy usage, to prevent overheating equipment, data centres require extensive cooling, which results in substantial water use. The IEA estimates data centres consume 560 billion litres of water annually, many of which are in drought-prone areas, with this estimate to rise to 1200 billion litres by 2030 (International Energy Agency, 2022). The number of global data centres has increased from 500,000 in 2012 to over 8 million in 2024, with energy consumption doubling approximately every 4 years (Thangam et al., 2024).

Dark Data

Perhaps most critically, 'dark data', information generated during digital activities that are never analysed or used, is estimated to comprise 60-90% of all stored data globally (*Dark Data*, 2022; Jackson & Hodgkinson, 2024)This reveals a fundamental inefficiency: data that offers no tangible value still demands substantial resources (Jackson & Hodgkinson, 2024). Not only this, but the environmental impacts of digital technologies, data centres, AI and dark data are interconnected. AI's dependence on data processing drives the growth of data centres, while dark data exacerbates storage demands (Jackson & Hodgkinson, 2024).

Fashion-Specific Challenges

The fashion industry faces a particularly complex combination of digital sustainability challenges due to its unique position as a globally distributed system spanning multiple stages and actors, from raw materials through to waste management. Climate change represents perhaps the most important challenge to system resilience at present, acting as a 'threat multiplier' that exacerbates existing vulnerabilities whilst creating new ones (Cullum, 2024). For fashion, these impacts manifest across physical, regulatory, market and reputational dimensions.

An emerging and increasingly complex dimension of resilience relates to the intersections and impacts of digitalisation on climate change. Digital technologies simultaneously offer potential solutions to climate challenges whilst creating new environmental impacts themselves (Lockwood et al, 2023).

The digital carbon footprint challenge

The fashion industry's digital carbon footprint is particularly high due to its global reach and rapidly changing trend cycles, with fast fashion now operating through 52 micro-seasons annually, each requiring new trend analysis, style development and production (Shaikh & Rane, 2025). This hyperaccelerated cycle means fashion companies, especially fast fashion retailers, are constantly generating and processing vast amounts of data across multiple operational touchpoints.

This results in data proliferation as brands gather extensive trend analytics, customer behaviour data, and supply chain tracking information across various points and networks worldwide (Johnson et al., 2024). The industry's infrastructure demands have grown accordingly, with global e-commerce platforms, real-time inventory management systems, and omnichannel retail experiences requiring continuous data processing and storage capacity. Much of this data remains predictive or analytical; some brands, such as Zara and ASOS, use this analytical data to feed AI-driven predictive analytics for demand forecasting, personalised recommendations, or to develop trend prediction algorithms (ASOS, 2024; Cao, 2024). This can enhance operational resilience to market fluctuations, and reduce overproduction, but simultaneously increase energy consumption.

Detailed production data is stored at every stage of the garment lifecycle, including 3D virtual design, sampling, design iterations, and manufacturing processes (Casciani et al., 2022). This rapid accumulation and storage of data has become a significant challenge for regulatory transparency, which is now beginning to necessitate complete lifecycle documentation of products (EU, 2024). This involves the collection and indefinite storage of even more granular data across entire supply chain networks. These practices illustrate the digital sustainability paradox: efforts to build operational resilience through digital technologies simultaneously undermine climate resilience by expanding energy consumption.

Regulatory Intensification of Digital Demands

Emerging regulatory pressures and frameworks further intensify digital demands. The EU's Digital Product Passports will begin to be implemented from 2028 under the EU's eco-design regulation (ESPR), becoming mandatory for all textile products sold in the EU market (EU, 2024). This means that comprehensive data collection and processing across entire supply chains will also be required for all garments sold in Europe.

Whilst these regulations are crucial for ethical transparency and accountability, they fundamentally transform data collection from an operational choice into a compliance necessity. Detailed DPP requirements won't be finalised until 2026, but current industry pilots such as the brand Nobody's Child indicate the scope of data demands requiring around 110 data points per product, including material sourcing, its carbon and water footprint and post-use care instructions, even linking customers to resale and rental services (McGregor, 2025; Oostermeijer, 2025).

The fashion industry's unique position, characterised by high visibility, consumer influence, and complex global supply chains, means its digital carbon footprint is not only highly impactful but also faces heightened scrutiny compared to less consumer-facing industries. However, these challenges also present opportunities for streamlined data management practices that could address both environmental and regulatory challenges.

Research Gap

Despite extensive research on digital transformation benefits in fashion, limited academic attention addresses the digital carbon footprint within creative industries (Casciani et al., 2022). Existing frameworks fail to integrate digital decarbonisation challenges with operational resilience requirements, creating a critical knowledge gap as industries face simultaneous pressures to digitise and decarbonise.

This raises the following key questions: How can fashion systems navigate the tension between digital technologies that enhance operational resilience while simultaneously undermining climate resilience through expanding carbon footprints? How can we manage the trade-offs between digital innovation and decarbonisation goals in creative industries?

The absence of industry-specific frameworks that address these interconnected challenges creates an urgent need for integrated approaches that balance resilience requirements with environmental imperatives.

Conclusion & Future Research

The fashion industry epitomises a critical challenge facing the creative industries: the digital sustainability paradox, where technologies that are supposed to help reduce carbon footprints (and enhance operational resilience) simultaneously undermine climate resilience through expanding digital carbon footprints. Current policy frameworks, including the DBT supply chain resilience model, and existing fashion-specific academic literature inadequately address the relationship between digital transformation and environmental impact (Casciani et al., 2022; Department for Business & Trade, 2022; NPSI et al., 2023).

The convergence of regulatory pressures and digital transformation creates an unprecedented opportunity for integrated solutions. The EU's Digital Product Passports, mandating comprehensive supply chain data collection from 2028, transform digital infrastructure from an operational choice to a compliance necessity (EU, 2024; McGregor, 2025; Oostermeijer, 2025). This regulatory shift presents a strategic advantage: digital decarbonisation through data cleansing and retention optimisation reduces carbon footprints while simplifying regulatory compliance (Jackson & Hodgkinson, 2024).

The fashion industry's characteristics (high consumer visibility, complex global supply chains, rapid AI adoption, extensive data requirements, and accelerated trend cycles) position it as an ideal testbed for developing integrated digital climate resilience frameworks (Casciani et al., 2022). Traditional resilience models prove inadequate under these conditions, necessitating fashion-specific approaches that simultaneously address operational resilience requirements, digital decarbonisation imperatives, and regulatory compliance demands.

Future research must develop and empirically test integrated frameworks that optimise digital technologies for both operational and climate resilience, while identifying specific policy mechanisms to scale these approaches across creative industries.

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Materials-First and Product-First Approaches to Creating Local, Circular & Bio-based Textiles in the HEREWEAR Project

Rebecca Earley
Chair of Circular Design Futures
University of the Arts London
United Kingdom

Guy Buyle
Manager
EU Research
Belgium

Lien Van der Schueren
Project Manager
Centexbel
Belgium

Nona Dokuzova
Co-Founders
Vretena
Germany

Denitsa Nika
Co-Founder
Vretena
Germany

Laetitia Forst
Post-Doc Researcher
University of the Arts London
Chelsea College of Arts
United Kingdom

Abstract

The HEREWEAR project aimed to establish a sustainable European textile ecosystem by developing locally produced clothing from bio-based materials. Addressing the drawbacks of conventional cotton and polyester, the project piloted cellulose and bio-based polyester textiles at semi-industrial scale. Over 50 prototype garments were created, combining innovative design with small-scale, on-demand production, via regional microfactories. Two design approaches were developed: a Material-First approach, exemplified in this paper by the presentation of the modular *Flexi-Dress* made from wheat-straw cellulose. The design of the dress emphasised multifunctionality and circular lifecycle extension

approaches. The Product-First approach is illustrated in the paper by the *Day Shirt*, which was designed to optimise monomaterial construction and recyclability approaches. HEREWEAR demonstrates the feasibility of integrating sustainable materials, design tools, and networked manufacturing to create a European circular, bio-based textile system, offering a practical model for environmentally and socially responsible fashion.

Introduction

What kind of new materials, design and production approaches might we need to develop if we are to evolve a biobased industry where clothes are created, used, reused and recycled in specific geographic regions? How can these clothes be made with less carbon emitted, and with lower chemical pollution from dyes and finishes? How can we ensure that these clothes release fewer microfibres into the water table when washed?

The HEREWEAR project asked questions that run deep in sustainable and circular design discourse. The project resulted in a new model for European regions to have local clothing, made from waste from agricultural waste with little or no value, designed to meet the needs of the people who lived amongst these natural resources. (Buyle *et al*, 2024) The project challenges included overcoming technical hurdles to transforming waste into viable, wearable textiles and designing clothes that would be loved for a long time and kept in use through repair and reselling. The project teams developed a series of prototypes to demonstrate possible responses to these challenges. The design and production process took either a *Materials-First* or a *Product-First* approach. These each represent a transferrable methodology for other interdisciplinary collaborative teams to adopt when tasked with making textiles and clothing that sit outside of existing industry models.

Context

Today, a large amount of clothing is produced in low cost countries, often far away from the brands designing them, under poor labour conditions and with few concerns for the environmental impact (Amed *et al.*, 2022). The vast majority of this clothing is made of two types of fibres; polyester and cotton (Textile Exchange, 2023). These, however, have considerable disadvantages and shortcomings. Polyester is oil-based and involves high carbon emissions, whilst cotton is a water and pesticide-hungry crop. There is therefore a need to divert fashion production from these resources and explore low-impact alternative fibres which reduce pressure on agricultural systems (Fashion for Good, 2025).

The design approaches describe here are set within a broader context of material innovation. As an alternative for cotton, cellulose filaments were made via wet spinning (using the HighPerCell® technology) of biowaste sources such as straw and seaweed was investigated. Instead of using fossil-based polyester, focus in HEREWEAR was on the use of polylactic acid (PLA) mixed with other bio-polyesters and processed via melt spinning to yarns. Whilst these new materials are viable alternatives to cotton and polyester, the present different qualities which must be acknowledged and overcome in the design process.

All prototypes within the HEREWEAR project were designed and produced in a holistic approach to advancing bio-based, circular and local textiles and clothing in Europe. This involved digitalization of the development and visualization of concepts, production in digitally connected local microfactory systems, and ensuring transparency and traceability through the Circularity.ID a digital product label developed by project partner circular.fashion. The Material-First and Product-First approaches were both set within these parameters of collaboration and circular design.

Materials-first and Products-first Approaches

Within the HEREWEAR project, the fashion brand VRETENA developed two prototype scenarios for ready-to-wear, urban garments designed to transition seamlessly “from Work to Streets”. These scenarios applied two distinct design methodologies: a Material-First Approach, in which the garment is created in direct response to the properties of a novel material, and a Product-First Approach, in which new bio-based fabrics are developed to replace the materials of an existing garment design.

The fabrics envisioned for these scenarios included a bio-based knit and a woven textile, both intended as sustainable alternatives to conventionally used fibres such as cotton.
The development process followed six structured steps:

1. Creative exploration using design guidelines and supporting tools.
2. Early prototyping to assess materials and production techniques.
3. Materials sampling to explore the performance of candidate fabrics.
4. Circularity checks and local modelling to ensure alignment with HEREWEAR criteria.
5. Digital design and simulation to test prototypes and prepare for production.
6. Creation of tech packs for implementation in the manufacturing stage.

The Flexi Dress: A Material-First Approach

The Flexi Dress was conceived as a response to HighPerCell® material from wheat straw, a bio-based cellulose fibre derived from unbleached wheat straw, which naturally exhibits a warm golden hue. This material emphasis created both an emotional and aesthetic connection to the fibre, while also advancing circularity through the avoidance of bleaching or dyeing steps.

The Flexi Dress (Figure 1) was designed as a versatile knitted garment that could be worn in multiple ways: as a complete dress, a separate top and skirt, or reversed to vary the neckline. This multifunctionality supports lifecycle extension by enabling the wearer to adapt the garment for different contexts. The design incorporated zero-waste pattern strategies and monomaterial construction, eliminating trims and additional hardware to facilitate recycling. Extensive knitting trials were undertaken to engineer joinable and separable garment parts without the use of additional fasteners. The resulting structure employed knitted slots and a belt system with denser knit zones for modesty.
The garment combined a modular construction, a silky tactile quality, and the inherent beauty of the unprocessed natural fibre. Its innovative approach was recognised with an award - Cellulose Fiber Innovation of the Year 2024 Award - at the 2024 Cellulosic Fiber Conference in Cologne, Germany.

Figure 1: The Flexi Dress 3D Design and garment simulation tool (left) and garment prototype (right)

The Day Shirt: A Product-First Approach

The Day Shirt was developed by re-imagining an existing VRETENA design originally produced in organic cotton. The aim was to replace this with a novel biopolyester woven material, demonstrating its potential as a breathable, skin-friendly and recyclable alternative.

Design-for-circularity principles were embedded into the garment: a monomaterial strategy was applied, and trims such as interfacing and buttons were removed. These choices facilitated recycling, while the aesthetic was deliberately positioned as a comfortable yet smart shirt with long-term emotional value.

A central technical challenge lay in overcoming the common drawbacks of biopolyester fabrics, which often feel stiff or "crunchy." Through iterative material trials and close collaboration between partners, a satin-woven biopolyester fabric was developed, achieving improved softness, drape, and coverage.

The final prototype (Figure 2), produced in a pale sage green, demonstrated that biopolyester can achieve both performance and aesthetic qualities suitable for ready-to-wear applications.

Figure 2: The Day Shirt - 3D Design and garment simulation tool

Conclusion

The HEREWEAR project has demonstrated that a sustainable European textile ecosystem can be advanced through the integration of bio-based materials, innovative design methods, and localized production models. At the material level, cellulose filaments derived from wheat straw and bio-based polyesters such as PLA were successfully developed and piloted at semi-industrial scale, offering credible alternatives to conventional cotton and fossil-based polyester. On a product level, prototypes demonstrating the wearability and desirability of these new fibres were developed.

The two design approaches explored Material-First with the Flexi Dress and Product-First with the Day Shirt highlighted complementary pathways for embedding sustainability into fashion. The former emphasized how new materials can inspire multifunctional, modular designs, while the latter demonstrated how existing products can be re-imagined with bio-based textiles to enable recyclability and extend usability. Both prototypes underline the importance of design as a lever for circularity.

A further cornerstone of the project is the HEREWEAR Hub (2024), established as a central platform for knowledge exchange, design guidelines, digital tools, and material libraries. By connecting diverse actors in the textile value chain, the Hub fosters collaboration, supports the adoption of circular and bio-based practices, and ensures that the project's outcomes are accessible and scalable beyond its duration.

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Embedding Regenerative Design in Design Education: A Framework for Interdisciplinary Collaboration and Climate Conscious Innovation

Suzanne Fallouh

Course Leader (Interior Architecture)

Faculty of Creative and Cultural Industries

School of Architecture, Art & Design

University of Portsmouth

United Kingdom

Karen Ryan

Programme Leader (BA (Hons) Fashion Marketing with Management)

Faculty of Arts and Humanities

Winchester School of Art

University of Southampton

United Kingdom

Katie Wilmot

Associate Head (Academic)

Faculty of Creative and Cultural Industries

School of Architecture, Art & Design

University of Portsmouth

United Kingdom

Abstract:

The built environment and fashion industries significantly contribute to resource consumption, energy use, and emissions, yet hold potential to drive positive change. Regenerative design shifts focus from minimising harm to creating benefits for human and natural systems. Preparing graduates for these challenges requires embedding regenerative competencies in education. This study asks: *How can regenerative design be embedded in design education through an interdisciplinary framework that prepares students for climate-conscious practice?*

We present a regenerative design framework integrating narrative, experiential learning, co-design, and systems thinking, co-developed through an Interdisciplinary Design Practice Framework and Mindset (Fallouh,2011). Piloted in the REGEN workshop, it united Architecture, Interior Architecture, Fashion, and Marketing students to explore lifecycles, circularity, and materials, using case study strategy and ethnographic, autoethnographic, and questionnaire methods. This framework offers a replicable, adaptable resource for educators seeking to embed regenerative design and systems thinking into their programmes, encouraging a shift from siloed teaching toward collaborative, embodied, and ecologically attuned learning. Findings highlight both its potential and the challenges of sustaining meaningful change.

Keyword(s): Circular Economy, Climate-Conscious Innovation, Design Pedagogy, Design Thinking, Interdisciplinary Design, Regenerative Design, Sustainable Future, Systems Thinking

Introduction

In the context of escalating environmental crises and the pressing demand for sustainable innovation, design education is central to preparing the next generation of regenerative thinkers and practitioners. The built environment and fashion sector both remain significant contributors to carbon emissions (UNEP, 2023; UNFCCC, 2018), resource depletion, and waste. However, these sectors also possess the capacity for transformative impact, particularly when emergent designers are equipped with systems thinking, material literacy, and collaborative skills. Regenerative design, which moves beyond sustainability by focusing on restoration and systemic healing, outlines an effective educational path. Transitioning to regenerative design in the fashion industry (Figure 1), and in the built environment requires a shift from viewing humans as separate from nature to recognising our interdependence with natural systems (Cole, 2017). Design education is central for enabling this shift, fostering systematic thinking, collaboration and regenerative values (Wahl, 2016). Design education is siloed and often lacks interdisciplinary regenerative frameworks. Despite increased attention to sustainability, disciplines and education remain fragmented (Stark, 2024; Chapman and Gant, 2007; Chapman, 2015), with disciplines taught in isolation and curricula focused on technical fixes rather than the holistic, transformative principles of regenerative design. This study, therefore, asks: How can regenerative design be embedded in design education through an interdisciplinary framework that prepares students for integrated climate-conscious practice in the built environment and fashion sectors?

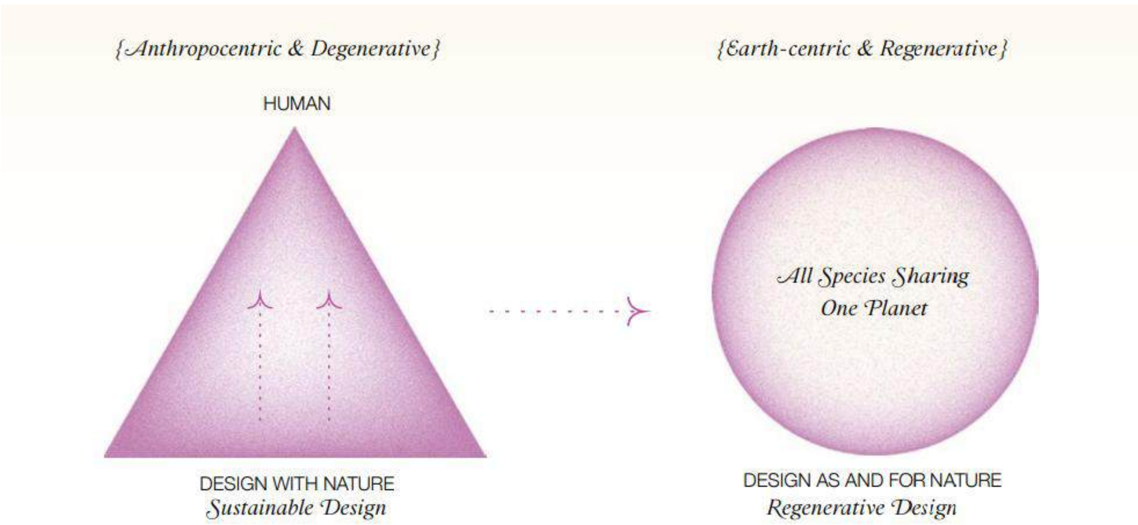


Figure 1: A paradigm shift towards regenerative design (Collet 2022, p.13)

This paper presents findings from a case study of the REGEN workshop, an interdisciplinary learning initiative in which the lead author's interdisciplinary framework and mindset a practice-led, cyclical model for interdisciplinary design practice was implemented and tested within the context of regenerative design. Building on doctoral research (Fallouh, 2021), which demonstrated how integrating spatial and garment design practices can transform designers' understanding through experiential learning, this study extends the framework to a collective pedagogical context, illustrating how regenerative design principles can be meaningfully embedded in design education. Having navigated the interdisciplinary integration process in her doctoral research, the lead author now applies these proven mechanisms within educational settings. The workshop fostered embodied, reflective, and collaborative learning processes that enabled students from adjacent design disciplines to become emergent collaborative agents of ecological and social change. This study, therefore, embeds regenerative design principles through an interdisciplinary design framework and mindset, demonstrates emergent collective pedagogical transformation, and bridges material exploration with systems thinking.

Incomplete Transitions: Current Limitations in Regenerative Design Education:

The transition to regenerative design education faces critical challenges. Despite emerging frameworks, current approaches remain constrained by disciplinary silos and limited knowledge integration. This analysis examines how current frameworks are limited in providing the interdisciplinary integration that regenerative transformation requires.

From Fragmented Sustainability to Collective Regeneration

As Hawken (2021) notes, the climate problem is a human problem rather than a scientific one (p.9). Human-made systems degrade ecosystems, drive inequality, and accelerate planetary destruction. However, sustainability's focus on efficiency, 'doing less harm', and incremental improvements has proven insufficient to address accelerating ecological crises (McDonough & Braungart, 2009; Reed, 2007). This limitation has prompted calls for regenerative approaches that move beyond harm reduction toward actively restoring and enhancing social-ecological systems (Mang & Reed, 2012). Regenerative design reframes humans as interdependent with natural systems (Cole, 2017). Such transformation requires moving beyond isolated sustainability measures toward holistic systems thinking through collective action through grassroots networks rather than institutional hierarchies (Hawken, 2021).

This need for collective transformation has profound implications for design education, which can act as a crucial incubator for the collective regenerative approaches that Hawken and Wahl identify as essential for systemic transformation. "What we need is an education for collective living rather than for individual success. The collective to which we need to pay more attention includes all the other species of this planet." (Goodwin, 2001, cited in Wahl, 2016, p. 134). Through collaborative, interdisciplinary learning experiences, students from diverse disciplines working together can cultivate both the technical competencies and collaborative mindsets necessary to build the grassroots professional networks capable of shifting design practice from fragmented sustainability measures toward integrated regenerative systems. These insights informed the REGEN workshop framework.

From Sustainability to Regeneration: Educational Frameworks, Pedagogies, and Toolkits

Design education plays a central role in enabling the regenerative transition (Wahl, 2016). International frameworks, such as UNESCO's Education for Sustainable Development: A Roadmap (2020), support transformative education by calling for interdisciplinary, action-oriented learning and highlighting the role of policy, learning environments, and community engagement. Design-oriented conceptual models such as McDonough and Braungart's (2002) ‘*Cradle to Cradle’* challenge the 'less bad is not good' approach of traditional sustainability, advocating instead for circular systems that eliminate waste through continuous material flows. These frameworks emphasise the shift beyond sustainability and frame education as a driver for transformation. These can be deepened by pedagogical approaches integrating narrative-based learning. Lambert (2013) shows how personal narratives connect individual experience to wider understanding, fostering the empathy and perspective-taking essential for regenerative design.

Building on these conceptual and pedagogical models, industry and collective initiatives have produced various toolkits for regenerative design education. Various sectors have developed toolkits, including Maison/0's regenerative toolkits for fashion (Collet, 2020) and the Circular Buildings Toolkit for the built environment (Arup & EMF, 2023), as well as ACAN's Climate Curriculum Education toolkit (2025). These offer strong practical sector-specific implementation, with some embracing holistic mindsets, reflection, experiential learning, and opportunities for narrative engagement.

Yet these frameworks and toolkits often remain siloed and lack interdisciplinary frameworks for regenerative practice. Working across disciplines requires new methods, processes and mechanisms to fully integrate dialogue between students from various backgrounds and engage various forms of knowledge. As Fallouh (2021) argues in her doctoral research, in interdisciplinary settings, multiple forms of knowing (tacit, experiential, embodied) (Polanyi, 1962) become essential yet remain difficult to foreground and integrate without frameworks specifically designed for cross-disciplinary exchange of this sort of knowledge (Fallouh, 2021).

Interdisciplinary Practice in Regenerative Education

Mang and Reed (2011) note, current approaches to tackling the climate crisis remain constrained within disciplinary silos, overlooking how these fields form integrated systems with communities. As discussed in the previous section, educational frameworks similarly exhibit fragmentation. Therefore, there is a need for interdisciplinary education that prepares future thinkers and practitioners to collaborate across fields, integrate diverse forms of knowledge, and engage in community partnerships for holistic regenerative practices.

To understand how such interdisciplinary education can be achieved, it's important to examine how knowledge integration occurs. Interdisciplinary knowledge emerges through integration processes (Repko, 2008; Wagner et al., 2011; Repko, Szostak and Buchberger, 2017). Figure 2 illustrates this integration process, adopted from Repko (2008).

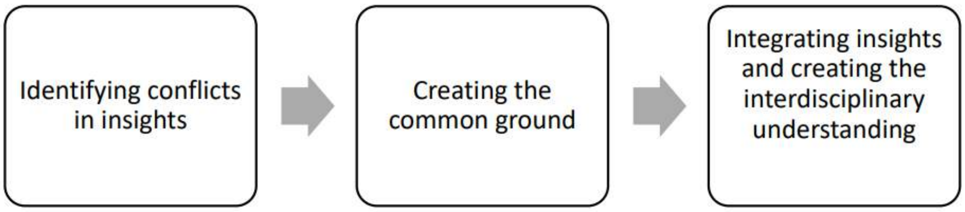


Figure 2: Integration process. Diagram by Fallouh, based on Repko’s (2008), (Fallouh, 2021)

Fallouh (2021) examined the interdisciplinary research and integration process in creative practice contexts, particularly between spatial and garment design (Figure 3). She found that integration begins with identifying a shared 'interface' but is neither automatic nor a simple method transfer. Instead, it emerges through situated practice in design projects, requiring material engagement and interaction with members of the *community of practice*, as described by Wenger (1998) and Wenger-Trayner et al. (2014). Fallouh further identified *experiential learning (drawing on the work of Kolb and Kolb, 2005; Kolb,2015)* as the primary mechanism for integration (p.320). The process both requires and fosters key interdisciplinary skills and traits: flexibility, metacognition, empathy, courage to explore unfamiliar territories, and perspective-taking (Repko, 2008; Repko, Szostak and Buchberger, 2017).

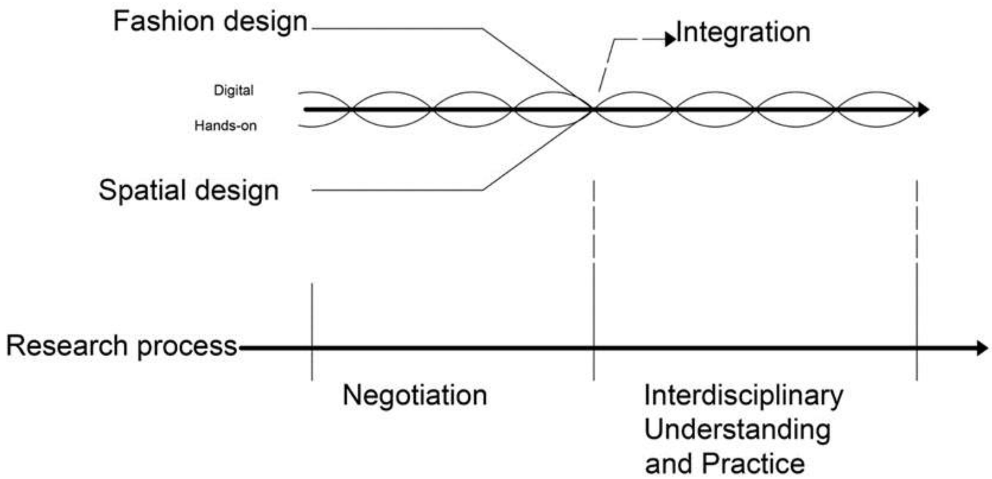
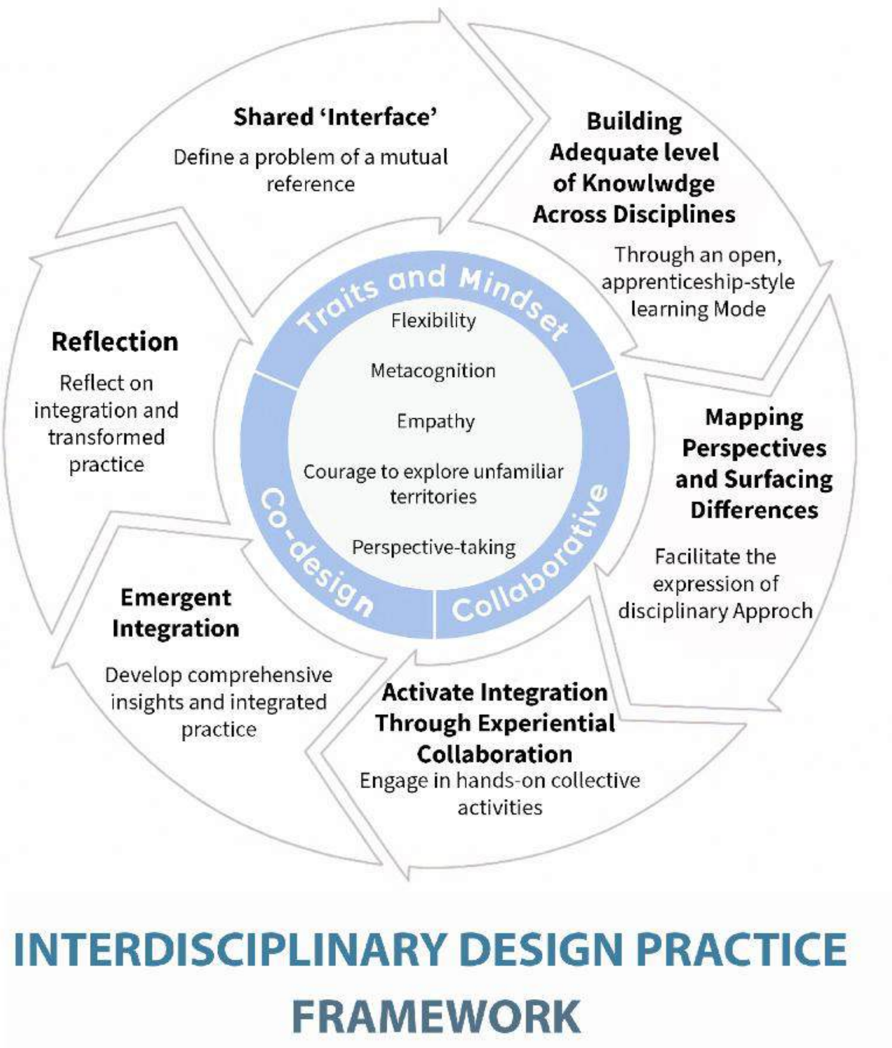


Figure 3: Visualisation of different stages and layers of Fallouh's (2021) interdisciplinary research process. Source:(Fallouh, 2021)

Building on Repko's integration theory, Fallouh (2021) developed an interdisciplinary practice-led framework (Figure 4) that positions experiential collaboration and ‘reflective practice’ (Schön, 1983), demonstrating how shared interfaces evolve into interdisciplinary insights through iterative cycles of knowledge-building and collaborative experimentation, with ‘tacit knowledge’ emerging and being exchanged through these embodied practices.

Repko (2008) identifies building an adequate level of knowledge in relevant fields as essential for integration. Fallouh (2021) extends this, arguing that in creative practice, this should be approached through an open, apprenticeship-style learning model. She positions creative practice as a central mode of inquiry that engages diverse forms of knowledge, particularly tacit and experiential, and enables the imagining and creation of new realities. Similarly, Stark (2024) reinforces these ideas, emphasising that addressing complex real-world problems requires 'artistic thinking' that integrates rational and creative approaches. Together, these insights informed the research and workshop framework, discussed in the following section.

Figure 4: Framework for interdisciplinary design practice integration (Diagram based on Fallouh, 2021). Source: authors



Approach & Lenses

This research investigates how regenerative design can be embedded in design education through interdisciplinary frameworks, preparing students for collaborative climate-conscious practice. The REGEN workshop (March 25 -28, 2024) served as a practice-led case study employing ethnographic observation, autoethnographic reflection, students presentations and and participants' questionnaire. Twenty-one students from architecture, interior design, fashion and fashion marketing UG and PG programs worked in balanced four interdisciplinary groups of 4-5 members. The workshop operationalised Fallouh's (2021) Interdisciplinary Design Practice Framework through four progressive days.

Data collection captured collaboration patterns, design processes, and reflective narratives, revealing how students negotiated disciplinary boundaries. While limited by a single iteration and educational context, the study demonstrates how experiential learning frameworks can operationalise interdisciplinary regenerative design education. Below is an outline of the progressive transformation through the four-day workshop.

Day One: opened the space for collaboration and identified a ‘shared interface’, introducing the climate emergency and required response as a mutual issue. Building an adequate level of knowledge in the relevant field practices. Starting with a natural dye workshop with oak gall ink on viscose fabric, established a shared material vocabulary and revealed disciplinary approaches to making. Groups demonstrated varying collaboration patterns documented through ethnographic observation (Figure 5).

Figure 5: Day one of the REGEN workshop. Source: authors

Day Two: building a level of knowledge in fashion design and garment making continued with subtraction cutting masterclass facilitated peer teaching, with fashion students instructing spatial designers in zero-waste techniques while exploring applications for architectural forms (Figure 6).

Figure 6: Day two of the REGEN workshop. Source: authors

Day Three: Following meditative grounding exercises and embodied activities which employed Ensō circle, students engaged with regenerative design and circular economy frameworks, debating greenwashing and sustainability urgency while addressing a design brief by developing pavilion concepts addressing full lifecycle considerations (Figure 7).

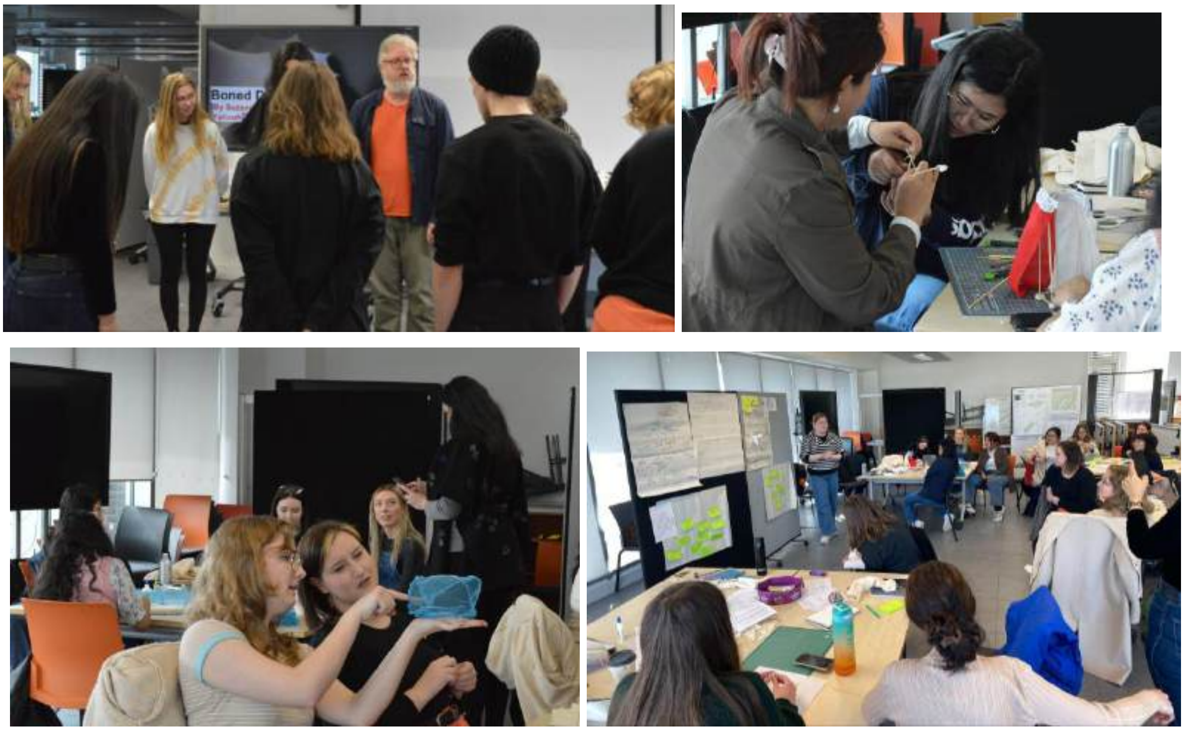


Figure 7**:** Day three of the REGEN workshop. Source: authors

Day Four: teams translated concepts into physical prototypes using constrained sustainable materials (bamboo, willow, recycled nets) with reversible joining methods, designing temporary pavilion sections addressing lifecycle considerations from sourcing through post-use (Figure 8), for instance, in Fashion Revolution Week exhibition (Figure 9). Final presentations demonstrated integration ranging from biomimetic structures to critiques of consumption, with documented evidence of interdisciplinary trait development**.**

Figure 8: Day four of the REGEN workshop. Source: authors

Figure 9: The REGEN workshop outcomes (left: teepee, middle: immortal lobster, right: butterfly pavilion/wearable armour) were exhibited as part of the Fashion Revolution Week. Source: authors

Findings: Integration Through Collaborative Making and Reflection

Data analysis followed Fallouh's (2021) integration framework, combined with transformative learning theory (Mezirow, 1996) and thematic analysis (Braun & Clarke, 2006). Analysis drew from a post-workshop survey, students' presentations and researcher observations, and design artifacts produced across the four-day workshop (Table 1).

Framework Stage	Survey Data (students)	Student Presentations/ Reflections	Researcher Observations / Interpretations
Conflicting Insights	"Fashion students go with the flow; architecture students are structured."	Some groups fractured (e.g., fashion students sidelined in structural tasks)	Observers noted disciplinary role fluctuation (fashion / spatial design). One reflection highlighted that students from fashion felt "out of the loop" when construction tasks dominated. Another observation described architecture-heavy groups panicking over time and structural instability.
Creating Common Ground	"Collaboration helps in creating something new"; "shared narratives"	Design metaphors of connection (tent, pavilion, lobster) unified disciplines	Researchers documented students explaining regenerative frameworks across subject boundaries, using them to negotiate design criteria. Other notes described collaboration improving over time, with processes acting as "conversation starters" or "icebreakers."
Achieving Interdisciplinary Understanding	"Not to be too stuck in my own practice"; "design the entire lifespan of your project"	Pavilion as chrysalis (fashion/architecture fusion); Gown as armour (nature, soil, climate change); Fast architecture = fast fashion	Observations recorded that students valued problem-solving and the new techniques learned. Facilitator reflections captured discussions critiquing greenwashing, urgency, and ethical issues across sectors. Other notes emphasised students' resilience, problem-solving, and adaptability under tension.
Regenerative Transformation Outcomes	Students expressed willingness for future co-design projects	Symbolic outputs embodied regenerative principles (chrysalis, tent, lobster tail)	Reflections highlighted affective transformation: empathy, humility, perspective-taking, tolerance of ambiguity, and meta-cognition exercises, emphasising critical reflection.

Table 1: Extract of three sets of data. Source: authors

Integration Process Analysis: the workshop revealed fundamental disciplinary tensions emerging most acutely during material practice transitions. Fashion students felt "out of the loop" when construction dominated, while architecture students expressed discomfort with textile ambiguity. One PG interior student characterised the divide: "Fashion students really go with the flow...architecture students are structured."

Material constraints proved the primary bridge across disciplines. The restricted palette forced collaborative problem-solving, exemplified by Group 4's approach: "we haven't actually used any fixings aside from string, so it can be dismantled." Peer teaching created reciprocal exchange fashion students instructing subtraction cutting while learning structural principles ccompanied by documented "laughter and giggling" suggesting comfortable boundary crossing, observed by the researchers.

Evidence of synthesis appeared in the final artifacts. Group 2's butterfly pavilion merged fashion's transformation narrative with architectural structure through "chrysalis shape...interactive...educational experience." Group 4's "mortal lobster" achieved the most sophisticated integration, critiquing greenwashing, sustainability's class exclusivity: "sustainability is only available...to those with money." However, Group 1's "collapsed tunnel" appears to reflect a less advanced stage of integration

Transformative Learning Outcomes: cognitively, participants reconceptualised design lifecycles from linear to cyclical. One student reflected on needing to "design the entire lifespan of your project" (Year 2 Interior). The discovery that "pavilion" derives from "papillon" created metaphorical bridges between disciplines. Affectively, students self-reported increased empathy, perspective-taking, and ambiguity tolerance during closing sessions. One interior student noted: "Learn how complex making a gown is...I admire fashion students/designers much more now." Behaviourally, documentation showed evolution from Day 1's "close physical proximity but limited discussion" to Day 4's fluid movement between spaces, with teams integrating outputs across environments.

Regenerative Design Understanding: initial engagement focused on material biodegradability. Groups emphasised degradable materials: "if everything goes, dies and deteriorates...it's going to degrade." This represents an important but limited understanding, focusing on end-of-life rather than systemic regeneration. More sophisticated groups demonstrated lifecycle thinking. Group 2's concept progressed from garment to shelter to soil enrichment: "gowns slash tent...eventually turn into fabric which could potentially go back to earth." This suggests emerging systems awareness, though practical feasibility remains unexamined.

The workshop's most significant achievement may be fostering a critical perspective on regenerative design itself. Students, in dialogue with researchers, questioned whether complete solutions exist: "nobody has the full picture yet. We're all trying to make parts of the puzzle." (researcher’s comment). This epistemic humility represents mature engagement with complexity.

Visual documentation reveals that narrative and metaphorical thinking emerged as an unexpected but crucial integration mechanism. Physical artifacts demonstrated varying integration success from the collapsed tunnel to the sophisticated "immortal lobster" concept. However, the most significant finding was how biological metaphors (warrior/armour, lobster/growth, butterfly/transformation) functioned as boundary objects enabling cross-disciplinary communication, suggesting symbolic thinking proved as important as technical skill transfer.

Each group's nature-inspired storytelling revealed different levels of critical engagement with regenerative principles. While Group 2's "eco-warrior" narrative positioned students as climate activists, Group 4's "immortal lobster" went further critiquing greenwashing and sustainability's class exclusivity and questioning who has access to regenerative futures. This progression from application to critique demonstrates that students developed agency to question rather than simply adopt regenerative frameworks.

The storytelling and narrative process appeared to foster student agency, with participants authoring their own relationships to regenerative practice rather than receiving prescriptive instruction. Survey responses indicated motivation for future engagement, yet this documented enthusiasm must be tempered with recognition that four-day workshop dynamics differ substantially from sustained practice. Whether narrative-based learning and the critical perspectives students developed persist beyond the workshop's supportive environment remains untested, highlighting the gap between initial engagement and lasting transformation.

Discussion: Examining Interdisciplinary Integration in Regenerative Design Education

The findings reveal that material limitations surpassed theoretical frameworks in fostering collaboration. While the restricted palette enabled Group 4's innovative string-only construction, the collapsed tunnel demonstrates that constraints alone cannot guarantee success—technical ambition must align with collective skills and time.

Beyond these practical challenges, a more fundamental tension emerged. Students' identification of the "urgency paradox" comparing rushed sustainability to post-WWII housing failures emerged organically rather than through the curriculum. This critical insight ("urgency to fulfil sustainability can be unsustainable") challenges fundamental assumptions about rapid transitions and suggests deeper engagement than intended.

However, the depth of this engagement must be contextualised within the workshop's temporal limitations. Observable changes from parallel to integrated working represent initial exposure rather than transformation. Without longitudinal data, claims of lasting change remain speculative. Positive self-reporting may reflect a workshop atmosphere rather than internalised learning.

Furthermore, even when collaboration occurred, it often reinforced existing disciplinary patterns. Architecture students naturally assumed management roles while fashion students led material manipulation, suggesting collaboration may reproduce rather than transcend hierarchies. Spatial arrangements positioning disciplines as "hosts" and "guests" potentially influenced participation patterns, requiring conscious attention in future iterations. These observations collectively illuminate both the strengths and limitations of the theoretical framework underpinning the workshop. The findings partially support Fallouh's (2021) framework while revealing unexpected dynamics. The framework's emphasis on experiential collaboration through material engagement proved sound successful groups achieved integration through making rather than discussion. However, the framework underestimated the role of critical questioning in learning. Students' interrogation of regenerative design's accessibility ("sustainability is only available...to those with money") suggests that transformative learning may require confronting contradictions rather than resolving them. The workshop created what Fenton-O'Creevy et al. (2014) term a "transitional space" temporary engagement with new practices without full identity transformation. This positions the workshop as preparatory rather than transformative, introducing vocabularies and methods that might enable future regenerative practice.

The workshop's outcomes reveal both progress and limitations in advancing beyond UNESCO's ESD framework toward regenerative practice. While students demonstrated critical capacities exceeding typical sustainability education questioning who has access to sustainability and identifying the urgency paradox these achievements emerged unevenly across participants. The finding that material constraints proved more effective than theoretical frameworks in fostering systems thinking and collaborative problem-solving suggests regenerative education requires fundamental pedagogical restructuring, prioritising tactile engagement over conceptual instruction. Although the workshop partially created a community of practice (Lave & Wenger, 1991) where Groups 2 and 4 achieved proactive, place-based thinking distinguishing regenerative from sustainable practice, this community remained temporary and bounded by workshop parameters. The interdisciplinary framework successfully extended ESD objectives through embodied learning students developed empathy, ambiguity tolerance, and critical reflection through making rather than instruction yet whether these represent genuine internalisation of regenerative dispositions or temporary workshop performances remains untested. The gap between ESD's aspirations and regenerative design's transformative requirements appears wider than four-day interventions can bridge, suggesting that cultivating true regenerative agency demands sustained engagement and institutional restructuring that challenges conventional academic structures.

Conclusion: Interdisciplinary Regenerative Education for Climate-Conscious Practice

This study examined how interdisciplinary collaboration might advance regenerative design education through the REGEN workshop case study, bringing together fashion and built environment students. The research employed qualitative and practice-led methods to investigate how regenerative design can be embedded in design education through an interdisciplinary framework that prepares students for climate-conscious practice.

Addressing the literature's identified gaps, the workshop moved beyond UNESCO's ESD framework of minimising harm toward regenerative practices that actively restore systems. The progression from fragmented disciplinary responses to integrated collaborative approaches, exemplified by students' systemic critique, shows how material constraints and narrative frameworks can operationalise regenerative principles.

Key findings indicate that material constraints effectively bridged disciplinary divides more successfully than theoretical frameworks. Students demonstrated initial engagement with regenerative principles through collaborative making, with varying degrees of integration success across groups. Most significantly, participants developed critical perspectives on sustainability's contradictions, identifying an "urgency paradox" that questions the pace and accessibility of regenerative transitions.

The workshop's contribution lies not in proving transformation but in identifying specific mechanisms that enable interdisciplinary dialogue. Material limitations, peer teaching, and embodied practices created conditions for knowledge exchange, though these remained bounded by temporal constraints and disciplinary habits. The emergence of critical questioning as a learning outcome, though unplanned, suggests that regenerative education benefits from examining its own assumptions rather than promoting uncritical adoption. Considerable limitations qualify these findings. The brief intervention period prevents claims about lasting change. Voluntary participation is likely skewed toward motivated students. The researchers' dual role as facilitators and observers may have influenced both workshop dynamics and interpretation.

Although the tested interdisciplinary regenerative framework requires iterative refinement, this research offers a replicable, adaptable resource for educators seeking to embed regeneration and systems thinking into their programmes. It encourages a move away from siloed teaching toward collaborative, embodied, and ecologically attuned learning. The workshop demonstrated that interdisciplinary regenerative design education is possible within constraints but challenging to sustain. Future research should examine whether initial changes persist beyond workshop contexts, how the framework translates to semester-long courses, and whether professional practice contexts enable similar integration.

The students' insight about the sustainability and regeneration urgency paradox may be the workshop's most valuable outcome not because it validates regenerative design, but because it reveals emerging designers' capacity for critical engagement with complex systems. If regenerative design education aims to prepare practitioners for uncertain ecological futures, fostering this critical capacity may prove as important as technical skill development. The question remains whether educational institutions can balance the urgent need for regenerative practitioners with the slower work of developing critical, reflexive, and genuinely transformative practice, underscoring the need for long-term commitment in education.

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Sustainable Design: Where Are We Now?

Professor Jeremy Faludi

Assistant Professor

Industrial Design

Delft University of Technology

The Netherlands

Sustainable design has evolved from early environmental awareness in the 1970s to modern frameworks such as the Circular Economy and Sustainable Development Goals. However, a major gap remains between academic theory and practical implementation. Hundreds of sustainable design methods exist but are rarely adopted due to limited testing and poor integration with industry workflows. Greater focus is needed on human-centred approaches to make these tools accessible and effective. Embedding sustainability in design education is equally essential, ensuring designers understand systems thinking, impact assessment, and innovation.

Sustainable design has changed significantly over the decades, from initial calling out of problems in the 1970s to EcoDesign and life cycle assessment, to biomimicry and Cradle to Cradle at the turn of the millennium, to today's system transition design, Sustainable Development Goals, and Circular Economy, to potential future post-growth paradigms. While some attribute this shifting landscape to inadequacies in past paradigms, the real problem is the gulf between theory and practice. Academic thought and literature have consistently been far ahead of industry implementation and education. Sustainability has shifted from radical fringe to "nice to have" to an imperative that even provokes backlash in some places. But it often still lacks effectiveness and ease of implementation to bring these beautiful theories of health, justice, and abundance for all into reality.

Bridging this gap requires better sustainable design tools and methods, along with improved adoption in industry. As outlined in "A Research Roadmap for Sustainable Design Methods and Tools" (2020), academia has produced hundreds of methods, but most are never used, or used only by their creators. They are usually created only from needfinding, with little to no user testing or iteration in industry to check effectiveness and appeal. It is like a company launching a physical product after showing a handful of users one or two prototypes in one or two iteration cycles. A new approach is needed a human-centered process to design our design methods so they get used, easily and effectively, at mass scale. And to integrate them into existing industry workflows.

Equally vital is embedding sustainability into design education at multiple levels, as argued in "Sustainability in the Future of Design Education" (2023). This manifesto for design curricula sets out core concepts that all designers must grasp, including sustainability fundamentals, circular economy principles, whole systems thinking, sustainable innovation strategies, impact assessment, and the socio-legal context of design (laws and labels). It also prescribes differentiated learning outcomes for three tiers of learners: all design students, those specializing in sustainability, and electives or advanced topics. In parallel, the Engineering for One Planet framework suggests a model for embedding sustainability in engineering education; it has been building momentum for years.

Such educational plans need curriculum to teach. The book Sustainable Design from Vision to Action synthesizes over 25 years of foundational concepts and advanced TU Delft research. It translates concepts into step-by-step guides for applying them in today's design workflows. It empowers both industry professionals and students to make evidence-based decisions and spark creative solutions, showing them, which tools and methods are best for different tasks and times in the design process. It covers all aspects of product design and the larger system (including diversity and inclusion, as well as business models). While this book and the papers above are not the only way to achieve a vibrant sustainable design future by 2035, they help lower the bar to implementation and raise the level of effectiveness, sparking industry and educators to embed sustainability deeply into their practice.

Cross-Functional Approach Towards Product Sustainability Implementation in the Household Appliances Sector: an Italian Case Study. Drivers, Limitations and Insights from Field Research Interviews

Stefano Ferraresi

PhD Candidate in Design

Department of Design

Politecnico di Milano

Italy

Barbara Del Curto

Full Professor

Department of Chemistry

Politecnico di Milano

Italy

Keywords

Ecodesign; Product sustainability; Material selection; Material innovation; Household Appliances; Corporate Sustainability; Organisational change; Sustainability culture; Sustainability drivers; Sustainable innovation approach; Case study research; Interviews; Participatory approach; Cross-functional collaboration

Abstract

A research project conducted in collaboration between Politecnico di Milano and a major Italian appliance manufacturer aims to define a cross-functional and participatory approach to advance product sustainability within this industrial sector. The paper outlines the overall research protocol and focuses on findings from preliminary interviews conducted during an extended field research period within the company. These interviews involved staff responsible for product-related decisions. Results include current materials and design choices' driver e.g., regulatory compliance and competitiveness. Perceived barriers to the implementation of sustainability-related actions are also presented, mainly related to operational and cultural aspects, such as the lack of a shared corporate sustainability background, ecotools, and structured processes. Accordingly, recommendations include fostering a sustainability culture, formalising internal guidelines, and defining clear objectives and KPIs. Methodological steps for subsequent validation and generalisation of the findings are described to ensure broader applicability of the approach. The study, still ongoing, confirms the potential of academia-industry collaboration for generating actionable insights, guiding organisational change, and supporting the integration of sustainability strategies in industrial contexts.

Premise

Delivering a sustainable transition within firms demands substantial commitment and cross-functional coordination underpinned by organisational capabilities and change processes (Amui et al. 2017; Castro-Lopez et al. 2023).

In the European context, the urgency of this transition for product manufacturers is underscored by a suite of legislative instruments acting across multiple phases of product development: material selection, product design, and information traceability under the Ecodesign for Sustainable Products Regulation (ESPR) (European Union 2024a) together with the Digital Product Passport (DPP), and the Critical Raw Materials Act (CRMA) (European Union 2024b); environmental claims and marketing communications under the Greenwashing (European Union 2024c) and Green Claims (European Commission, 2023) initiatives; downstream activities following sale under the Right to Repair Directive (European Union 2024d) and national measures such as France's AGEC law (République Française 2020); and, more broadly, the promotion of Circular Economy principles implementation for industries through wider initiatives such as the Circular Economy Act (European Commission, Directorate-General for Environment 2025), currently under public negotiation.

In parallel, technical standards are defining requirements for tracking and exchanging information on product circularity along the value chain in an interoperable manner e.g. the Product Circularity Data Sheet (ISO 2025a), as well as methodological guidelines for integrating circularity into the product design and development process – focusing on material efficiency and trade-offs without compromising product functionality and safety – set out in EN 45560 (ISO 2025b), part of the EN 4555x-4556x family on durability, reparability, reusability, upgradability, remanufacturability, use of reused components, recyclability and recycled content; and communication on critical raw materials.

Consequently, for firms it becomes critical – within the continually evolving framework of corporate sustainability – to integrate specific objectives and strategies for product sustainability, alongside the capabilities required to measure it using standardised criteria and methodologies such as Life Cycle Assessment (ISO 2006a,b; Zampori et al. 2019).

Introduction & research aim

Along this sustainable transition pathway, collaboration with the research community can help to inform and steer the change process. Moreover, fostering sustained dialogue and partnership between academia and industry represents a valuable opportunity to generate fruitful synergies: scholars, as privileged observers of emerging research agendas, can offer innovative, scientifically robust and long-term methodological insights, while companies can, in turn, sharpen researchers' awareness of the real-world challenges faced by industry. As illustrated by Andriamanantena et. al. (2025), external collaboration with industry networks, NGOs, and research institutions – including universities – is a critical determinant for the effective implementation of sustainability-oriented strategies in traditional enterprises. Furthermore, as stated by Hervas-Oliver et al. (2021), collaboration between academia and industry is a key driver of innovation across European regions, often exerting an even greater effect than internal R&D investment, particularly in intermediate-innovation contexts such as Italy.

Building on this premise, the Italian institutional initiative 'From Research to Business' (MUR 2023) – under which the Ministry of University and Research co-funds PhD research projects alongside Italian companies – aims to support sustainable innovation. One such project, co-financed by a large (European Commission, 2003) Italian household appliance enterprise and currently conducted by the authors, pursues the development of a novel holistic cross-functional approach to product sustainability that integrates sustainability-oriented material selection – to ensure a responsible and circular use of resources – with ecodesign – to reduce impacts along the product life cycle – tailored to the appliance sector.

To date, at least regarding scholarly knowledge, both material selection (Ashby 2022; Ashby 2012; Ashby & Johnson 2013) and sustainable and circular design (Bakker et al. 2014; Bhamra & Lofthouse 2016; Bocken et al. 2016; Clark et al. 2009; Vezzoli & Manzini 2008) are individually broadly explored fields and can count on major literature contributions. However, these theoretical approaches although potentially valid are sometimes not actually and efficiently implemented in real business contexts. This implementation gap affects the full exploitation of the competitive advantage and environmental benefits that such methodological strategies and processes could offer if introduced from the early product design and material selection phases. Instead, introducing these concepts would enable household appliance manufacturers to be prepared for if not anticipate the increasingly strict regulatory framework, thereby ensuring product compliance.

Accordingly, this novel approach aims to be guided by, and informed through, field research within a company case study and Participatory Action Research (PAR); and enable the systemic (Bistagnino 2011) diffusion of product sustainability within the company context, extending beyond sole designers and engineers to the cross-functional actors who shape and operationalise the integrated product strategy.

This contribution presents the overall research strategy of the project and discusses the preliminary findings from the interviews carried out during the field research conducted within the above-mentioned company.

Methods

PhD methodological approach

The PhD research, based on a mixed-methods approach, involved a 9-month field research period at the corporate headquarters in Italy. During this period, a two-phase research protocol composed of the strategies described hereafter has been followed.

1) To map the company context, understand the current ('As-Is') state of product sustainability-related practices and the main stakeholders, on-site observations as well as unstructured and semi-structured interviews were conducted, as described in detail in the following paragraph.
2) Based on the findings from on-site observations and interviews: (2.1) A briefing was convened involving nineteen top managers and directors from company functions identified as product-impacting (i.e. Procurement & Logistics, Mechanical Design Department, Electronic Department, Product Management, Marketing & Communications Department, Project Management, Product Compliance Office, Laboratories and R&D Department). During this session, key concepts relating to product sustainability – intended for integration within the company culture – were presented to highlight their strategic importance, along with a cross-functional activities plan aimed at transferring these concepts to relevant departmental staff. (2.2) Subsequently, in collaboration with the top managers and directors of functions who participated in the briefing, a total of eighty-three individuals from various functions and differing levels of seniority were identified. This group was then involved in training initiatives and participatory activities (workshops and focus groups) centred on product sustainability (e.g. Circular economy concept and principles, ESG criteria, corporate sustainability fundamentals, design for sustainability methods and tools, LCA and some insights on the EU legislative framework). The effectiveness of these activities was assessed using questionnaires administered before and after the process.

Semi-structured and unstructured interviews – Methodology and objectives

An in-depth case study research was conducted using the partner household appliance company as the analytic unit, during the aforementioned period of field research. To map the organisational context, semi-structured and unstructured interviews were carried out.

In collaboration with a corporate tutor, the researcher selected sixteen candidates at different working career stages (Chourasiya & Agrawal 2019; Super 1980) from departments whose decisions influence the product, ranging from product strategy definition, through design and testing, to final communication. The technical staff interviewed are involved in the design of major appliances. Additionally, two representatives from the Legal & CSR Department, responsible for CSR topics and the drafting of the Sustainability Report, were interviewed.

An overview of the company departments to which the interviewees belong, as well as their career stage, is provided in Table. 1.

Department	Working Career Stage (Super, D. E., 1980; Chourasiya, A., & Agrawal, V., 2019).
Project Management	Establishment
Product Management	Establishment
Product Compliance Office	Maintenance
Product Compliance Office	Establishment
Mechanical Design Department	Maintenance
Mechanical Design Department	Maintenance
Mechanical Design Department	Establishment
Mechanical Design Department	Establishment
Mechanical Design Department	Establishment
Electronic Department	Establishment
Laboratories and R&D Department	Establishment
Health, Safety & Environment (HSE) Department	Establishment
Marketing & Communications Department	Maintenance
Marketing & Communications Department	Establishment
Procurement & Logistics	Maintenance
Procurement & Logistics	Maintenance
Legal & CSR	Establishment
Legal & CSR	Establishment

Table 1 – Details of the interviewees.

The interviews were conducted in person, each lasting between 45 minutes and one hour. The topic guides were designed in accordance with qualitative research interviewing guidelines (Harvey 2011; Bryman 2016; Kvale & Brinkmann 2009; Kvale 2007).

The interviews allowed researchers to map product-related decision-making processes, as well as the roles and interactions among departments responsible for product design and materials selection. They enabled the identification of current drivers for design and material choices, provided an understanding of the present ('As-Is') level of integration of product sustainability methods and tools, and, crucially, helped to pinpoint factors perceived as limiting the implementation of sustainability-related initiatives and to highlight potential areas for improvement to better steer the company towards sustainability, as indicated by the interviewees.

To extract information from the interviews, qualitative research analysis methods were applied (Belotto 2018). In particular, the interviews were transcribed and subjected to thematic analysis (Alhojailan & Ibrahim 2012).

Findings & Discussion

This section presents and discusses the main findings from the interview analysis. Specifically, it first addresses the investigation of current drivers for product design and material choices. Then, it examines employees' involvement in product sustainability-related projects and the integration of ecodesign and material selection tools into current practice. Finally, it highlights the critical factors that nowadays limit the implementation of sustainability-related actions, as well as the areas for improvement that could better guide the company towards sustainability.

Product design and materials choices 'drivers

Product design drivers

The interviews clearly indicate that when it comes to product design, the most cited drivers are economic competitiveness/costs (8 out of 16 respondents) and regulatory compliance (7/16). Notably, most interviewees also cited these drivers as the most important when asked to rank them in order of significance. Quality was another driver mentioned by the interviewees (4/16), which aligns with the company's objectives, as its Sustainability Report materiality matrix highlights quality as one of the most significant product-related aspects. Finally, feasibility and functionality (3/16), as well as design for assembly (4/16), are regarded as important by a significant minority. The technical feasibility and manufacturability of the product are especially relevant, given that many production and assembly lines are managed internally within the company.

Materials choices drivers

For material selection, regulatory compliance figures even more prominently (9/16), since appliances are subject to various regulations – often cited by interviewees – such as REACH, RoHS, and those relating to food contact. In this regard, three interviewees explicitly mentioned food contact and avoidance of hazardous materials. The second most cited driver is again economic competitiveness/costs (8/16). For material selection as well, important drivers are quality (4/16) and aesthetic properties (5/16), in line with the company's strategic approach and brand positioning towards quality and premium perception. Another important driver (3/16) relates to the technical properties of materials, and in particular to mechanical properties, thermal ones, and resistance to certain environments or chemicals. In material selection, suppliers also play a pivotal role: three interviewees stated that their proposals can be a driver of materials' innovation, and three of them emphasised that suppliers' proximity is a decisive factor. Nonetheless, material selection can also be influenced by considerations related to supply chain robustness and procurement.

Figure 1 shows an overview of all the drivers mentioned by the interviewees. This breakdown underlines how decision-making for both product design and material selection tends to be mainly led by economic factors and regulatory compliance, and this is consistent with the drivers identified in other similar studies conducted on household appliance companies (Piselli et al. 2016; Zhou et al. 2023).

However, the current lack of a structured approach towards sustainability is reflected in the absence of sustainability-oriented drivers reported in both domains.

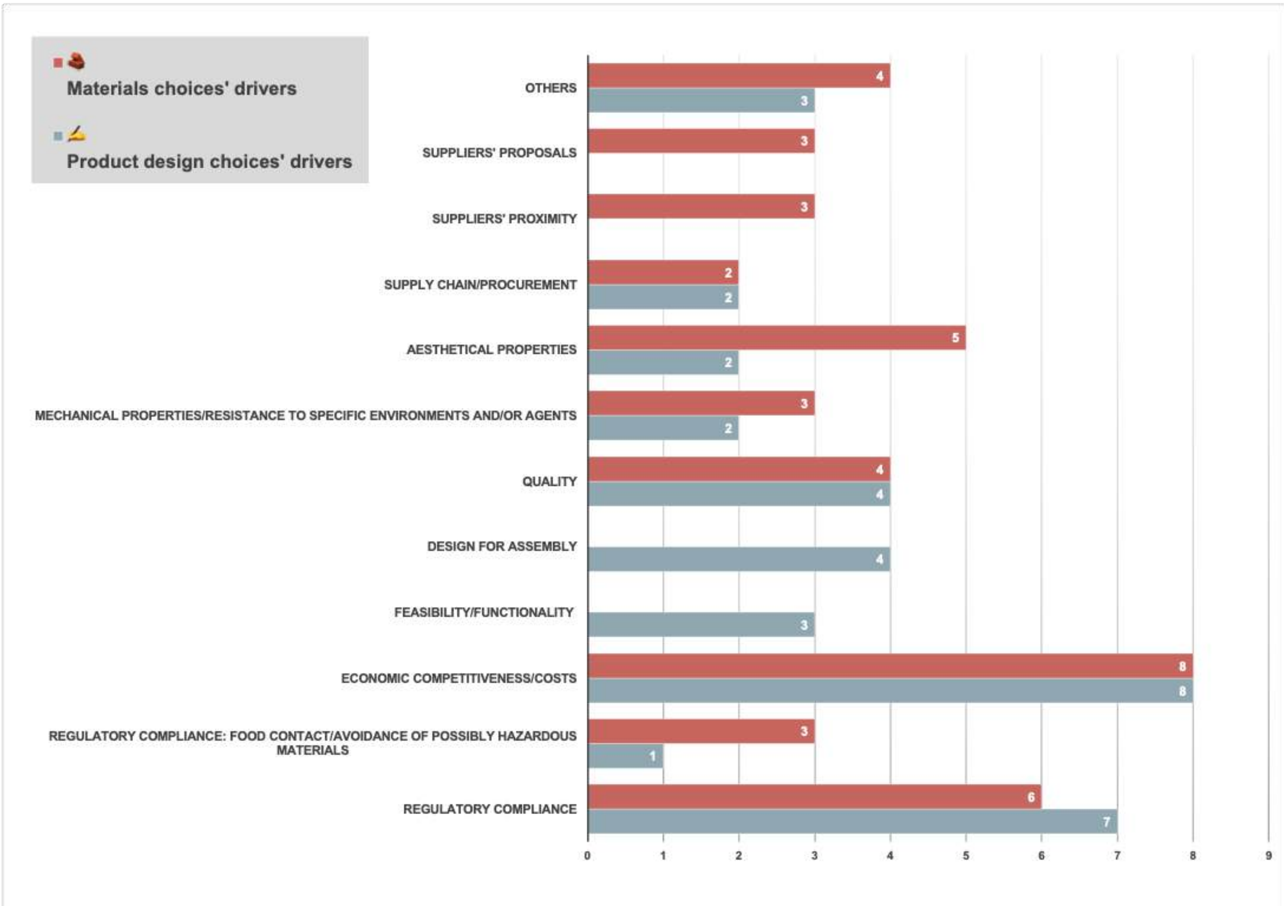

Figure 1 – Product design and materials choices' drivers reported by interviewees

Current product sustainability-related projects, practices and tools

Projects and actions

When asked to name product sustainability-related projects or actions they had directly participated in within the company, or of which they were aware, interviewees mentioned two main initiatives: a major project to progressively eliminate EPS from packaging in favour of paper-based solutions (mentioned by 9 out of 16 respondents); and a pilot product LCA project (5/16) involving multiple departments for the collection of primary data. Among other individual actions, two respondents reported the avoidance of materials containing PFAS, while another two cited the implementation of secondary materials, such as recycled paper for instruction manuals or a recycled copolyester grade for certain product components.

This shows that some punctual actions, which can affect the environmental impact of products and packaging, have been implemented; however, the primary driver behind such actions is typically not the sole sustainability, but rather regulatory compliance (e.g., upcoming national ban on the use of EPS), which in fact is among the main drivers mentioned for design and material choices. Thus, at present, the results suggest that the company's prevailing approach is compliance-oriented.

Tools

With respect to the use of tools supporting sustainability-oriented design (ecotools) and material selection, 10 out of 16 interviewees stated that currently these are not applied, except for some limited pilot actions. Two respondents indicated that, at times, knowledge-based guidelines are followed to improve product durability and reparability. One interviewee stated that although ecotools are not yet applied on a large scale, this is a goal to be pursued and one that the company is working towards, requiring considerable effort to be effectively and seamlessly integrated; furthermore, some respondents indicated that the use of filing templates and material selection tools could support sustainability-oriented design practices.

This demonstrates that there is both space and willingness to move forward with the integration of such supports, and the main factor causing this implementation gap is related to the complexity of integrating these tools into operational practice.

Factors limiting sustainability-related actions implementation and areas for improvement

Limiting factors

The main limitations to sustainability-related actions implementation reported by interviewees are visualised in (Fig. 2). The most frequently cited barriers (mentioned by 8 out of 16 respondents) are related to increased lead times (such as additional product design steps, extended time-to-market, etc.) or higher costs (e.g. the price of alternative materials, etc.). Half of the respondents also perceive the lack of training or shared sustainability culture as a barrier, and five the lack of dedicated personnel. Respondents (5/16) also highlighted as a limiting factor the lack of tools (e.g. ecotools), the difficulty in retrieval or unavailability of certain data, and the complexity of identifying effective metrics to measure sustainability actions. The lack of structured approaches and explicit prioritisation of sustainability – expressed as the absence of specific goals or KPIs – was noted by three respondents respectively. Limited communication and collaboration among departments, as well as the perceived effort required for the transition, were reported less frequently (2/16 responses apiece). Finally, among the individually mentioned barriers – grouped under 'others' – respondents highlighted the complexity associated with the breadth of the product portfolio, as well as issues related to controlling the end-of-life of environmentally critical components, such as electronic components.

These findings indicate that both operational and cultural factors hinder a more effective and widespread implementation of sustainability initiatives within the company.

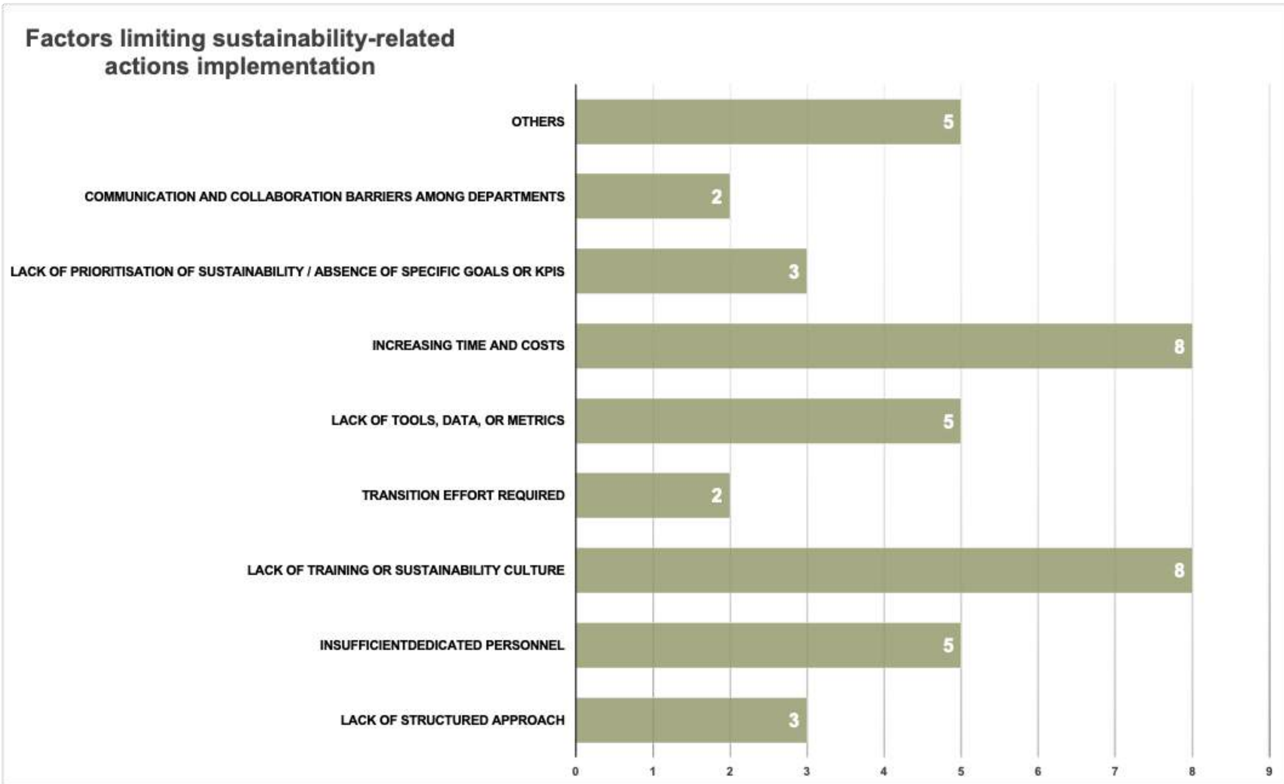

Figure 2 – Factors limiting sustainability-related actions implementation reported by interviewees

Areas for improvement
Possible areas for improvement to better steer the company towards sustainability, reported by interviewees, are visualised in (Fig. 3). The most frequently suggested intervention is the definition of structured approaches (both at the organisational level and at an operational scale) and the statement of clear internal guidelines (7/16), underscoring the need for formalised processes. Provision of training activities on sustainability is recommended by 5/16 respondents, recognising the staff awareness and competence as a key enabler. Setting clear sustainability goals is put forward by 4/16, while defining criteria for materials and finishes selection is cited by 3/16 as an action to support an eco-informed decision-making. Increasing interdepartmental communication and enhancing the provision of proper tools to support sustainability integration were considered enablers by two respondents, respectively. Three respondents suggest that developing an effective sustainability communication strategy towards customers and stakeholders is crucial, a process which is currently underway within the company.

These recommendations indicate a consensus towards structured organisational change, targeted training, and improved clarity in sustainability processes and objectives.

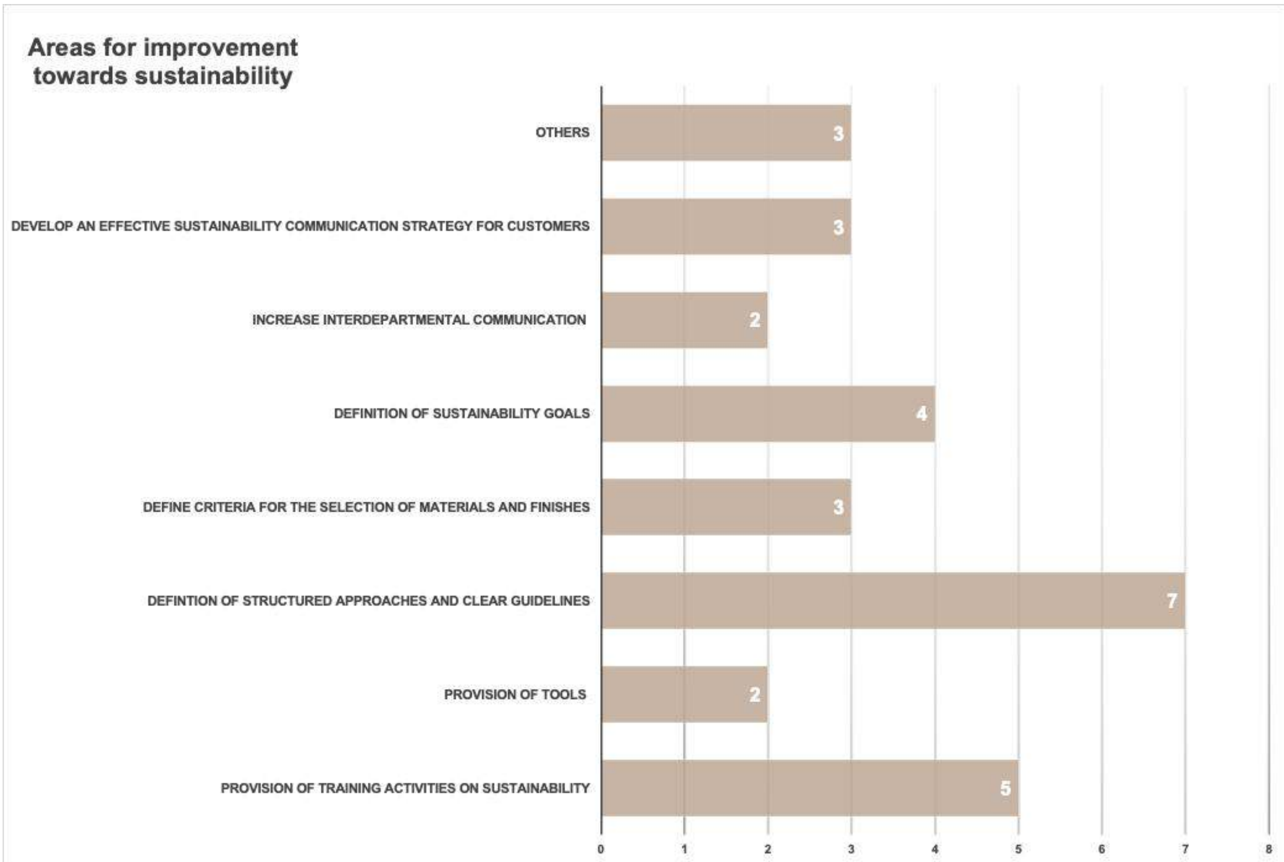

Figure 3 – Areas for improvement to better steer the company towards sustainability reported by interviewees

The analysis reveals a strong alignment between the main barriers hindering sustainability practices and the improvement areas proposed by interviewees. Notably, the lack of structured approaches, clear internal goals, and explicit prioritisation of sustainability – cited as significant limitations – are directly addressed by the most frequently suggested improvement: developing formal processes and clear organisational guidance. Similarly, the absence of a shared sustainability corporate culture and insufficient training, both considered major obstacles, find a direct counterpart in the recommendation to implement targeted training activities to enhance staff awareness and competence.

Operational challenges, such as the lack of adequate tools (e.g. LCA software applied at scale), difficulties in collecting data and defining proper metrics, are mirrored in the suggested provision and enhancement of tools and supporting infrastructures. The issue of limited interdepartmental communication and collaboration, though less frequently reported as a barrier, is echoed in the proposals for increasing internal communication channels and cross-functional integration.

Additional recommendations, such as setting clear sustainability guidelines and criteria for materials selection, reflect an effort to overcome the current lack of explicit targets and support more informed eco-oriented decision-making. The ongoing process of developing an external sustainability communication strategy is also shaped in response to the need for clarity, both internally and in stakeholder engagement.

In synthesis, the areas for improvement identified by stakeholders closely correspond to the array of cultural, organisational, and operational barriers encountered, suggesting a certain degree of awareness within the company regarding the pathways needed to advance its sustainability agenda. The alignment also indicates that progress will largely depend on the systematic translation of these recommendations into concrete, coordinated actions across the organisation.

Additional insights from Legal & CSR Department

To complete the picture of the 'As-Is' state of product sustainability within the company, the perspective of the candidates directly responsible for product-related decisions was supplemented by interviews with two representatives from the Legal & CSR Department, who are responsible for one of the main sustainability-related corporate activities: drafting the Sustainability Report.

With regard to the European regulatory framework on product sustainability, the interviewees emphasised that appliance companies will soon be required to comply with the prescriptions defined for each product category by the delegated acts of the ESPR framework Regulation. In addition, the drafting of the sustainability report will need to align with the new standards set by the CSRD Directive. As a result, one of the main drivers prompting companies to take action on sustainability will primarily be regulatory compliance. Other increasingly decisive drivers include growing consumer (B2C) and customer (B2B) sensitivity toward sustainable products, as well as heightened scrutiny by banking partners of corporate sustainability policies and ESG criteria.

The interviewees also pointed out that the company's sustainability report, published voluntarily for several years, has been useful in measuring the organisation's impacts (i.e. carbon footprint). Among the key future improvement areas identified was the need to move beyond impact measurement alone, progressing towards the definition of targets and actions for impact reduction, along with the creation of a comprehensive sustainability strategy that spans the various business units across the corporate structure. For product-specific challenges, one of the most critical future tasks will be the large-scale implementation of Life Cycle Assessment.

Project perspectives and next steps

Some of the critical issues and limitations highlighted in the interviews have already been subsequently addressed through the training initiatives and participatory activities mentioned in section (2.2) of the Methods. These activities have provided a shared grounding in product sustainability culture, giving the necessary theoretical and methodological foundations. Furthermore, the main ecodesign and material selection tools were presented and discussed with those in operational roles related to the product, to begin spreading awareness and to evaluate the advantages and disadvantages of the available options.

Cross-functional workshops and focus groups also allowed for mapping the as-is state of product development and for initiating discussions to identify ideas and pathways for improvement. Not least, these activities have been occasions for collective exchange and dialogue among different functions within the company.

On a methodological level, the project's strategy involves two additional steps. Firstly, another 3 months of field research within the company is planned, during which further product-focused workshops will be conducted for the technical functions. In parallel, through Participatory Action Research, to validate a robust and practically implementable strategy, directions and guidelines to steer change will be proposed, discussed and refined together with management to assess their feasibility. This will serve as one of the metrics for evaluating the successful transfer of concepts from academia to industry (Cook et al. 2006). Secondly, for the purposes of generalising the approach, a cross-sectoral validation is planned to be carried out through interviews with experts (e.g. sustainability consultants) and professionals from other corporate contexts.

Conclusions and limitations

This study has demonstrated the necessity of organisational commitment and cross-functional coordination for advancing product sustainability within the studied appliance company, especially as regulatory, market and societal pressures intensify. The findings clearly indicate that, while compliance and competitiveness remain primary drivers of material and design choices, progress towards sustainability is frequently hindered by operational barriers, cultural inertia, and the lack of structured approaches and dedicated tools. Crucially, the results highlight how awareness of these challenges is growing within the organisation and suggest that targeted interventions – such as the provision of sustainability training, formalisation of internal guidelines, and the establishment of clear goals and key performance indicators – are essential to overcome progress barriers.

In this context, the cross-functional and participatory research approach has provided valuable insights into both the limitations encountered and the pathways for improvement. Collaborative research, systemic thinking, and continued dialogue between academia and industry are shown to be critical in driving the cultural and organisational change required to embed sustainability in product development practices. Future work will focus on validating the proposed strategies within the company and also on ensuring the generalisability of the findings by engaging with external experts.

This last step addresses the main potential limitations of the project, namely its focus on the company case study, which may restrict the direct applicability of the findings to other organisational contexts or sectors. Further limitations are connected to the data gathered through interviews and participatory workshops, which reflect subjective perspectives that could be influenced by individual backgrounds and organisational dynamics. Methodological constraints, such as the limited sample size and the challenge of capturing long-term effects in a short research timeframe, may also affect the comprehensiveness of the insights generated.

As concluding remarks, collaboration between industry and academia is proving to be effective in addressing the corporate gaps around product sustainability and in building a long-term vision grounded in research insights and capable of supporting the definition of specific objectives and KPIs, which are essential for real progress and to measure it.

Finally, one-to-one interviews and the researcher’s presence within the firm have been crucial in building staff trust and credibility, enabling active participation and support for ongoing project activities.

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Influencing Motivations: Exploring how Social Media Influencers and Voucher Schemes may be Fuelling a Pre-owned Denim Revolution

Dr Jules Findley

Principal Lecturer

University of Brighton

School of Art and Media

United Kingdom

Dr Martin Bouette

Senior Lecturer, University of Brighton

University of Brighton

School of Art and Media

United Kingdom

Claire Dawson

PhD student

University of Brighton

School of Art and Media

United Kingdom

Abstract

Influencers are demystifying the concept of second-hand clothing to a younger generation (Confidential Couture, 2024). Additionally, the second-hand market grew globally by 28% in 2022, and it is anticipated to reach $350 billion by 2027 (ThredUp, 2023) allowing brands to leverage this interest by selling second-hand items directly. Sustainable denim brands including Nudie and MUD jeans ask consumers to return used denim from the brand in exchange for a discount incentive. Returned items are repaired or recycled (MUD Jeans, 2024) or repaired or resold (Nudie Jeans, 2024).

This paper explores the impact of social media influencers on the pre-loved denim clothing sector profiling E.L.V. Denim. Additionally, it documents incentive vouchers and discounts offered by seven denim brands from SMEs to global players. It identifies some key challenges and opportunities for the future including growing affluence in the Global South, and how UK policy changes could strengthen this business model.

Introduction

Through an examination of the role of the social influencer we explore the notion of second-hand and upcycled denim as both a fashion decision and as an indicator to sustainable thinking and behaviour in both the Global North and Global South. We argue that the pre-owned denim market is more complicated than simply reselling second-hand denim and that there are cultural influences that may influence purchasing decisions. We also analyse whether social media influence has fuelled a pre-owned as fashion or as a sustainable decision and whether buy back schemes support sustainable decisions or fuel purchases of new products.

In 2024, WGSN revealed that 40% of Gen Z buy preloved or second-hand clothes as they could not find the style they were looking for from high street retailers. In terms of fashion trends, Gen Z is driven by nostalgia, a looking back at their childhood, their parent's music and clothing, to escape the harsh realities of daily life. Anxiety is the highest reported emotion from Gen Z which is evident in all aspects of the work and higher education environments. (WGSN, 2024).

Some retailers have developed voucher schemes. These schemes allow consumers to exchange old items of clothing for a voucher that can be used to buy new items. This can be seen as both a way of collecting fabric for recycling, resale or upcycling but can also be seen as a marketing ploy to promote the purchase of new items.

As part of this study an interview was conducted with E.L.V. Denim. The interview was conducted at E.L.V's premises in London exploring the connection between the brand, social influencers and their perceived importance of minimising all waste.

To extend lifespans, garments need to be physically and emotionally durable to ensure the full economic and environmental value captured and kept in circulation for as long as possible. (Ellen Macarthur Foundation, 2023). This paper explores the impact of social media influencers on the pre-loved clothing sector and voucher incentives for denim take-back programmes.

Growth of second-hand

Gen Z seek comfort in the small things that bring happiness, this includes nostalgic style. They use various platforms such as TikTok, Depop, Vinted, to shop and sell their clothes to update their wardrobes. (WGSN, 2024). Can influencers make a difference in sustainable choices, and promote responsible purchasing? These ideas were promoted in 2023, with the UN Fashion Communication Playback Book. (www.unep.org, 2023).

There are various markets that are nuanced in second-hand denim, these include online second-hand clothing markets, such as Vinted, Depop and eBay, where ordinary people sell used clothing taking their own photographs uploaded to these sites for various prices. There are other platforms such as Thrift, GoThrift, Grailed, GOAT, and Loopi among others which sell curated second hand clothing. GoThrift have seen rapid growth in three years, from a founder of four based in the Northwest of England, now employ over 40 people, selling over 300,000 items, with a rise of 175% and an estimated revenue of £4.4 million in 2023. (Oneplanetcapital, 2025)

The rise in second-hand denim sales links closely to the growing popularity of second-hand clothing connected with the term 'vintage'. The growth of online stores curating vintage and denim products shows a change away from the idea that new is better, sales are driven by sustainability, style and economics. The environmental benefits for each second-hand piece of clothing displaces 8kg of Co2 and reduces emissions relative to a new garment by 82% is one of the main reasons to keep garments in circulation for longer. (Oneplanetcapital, 2025)

These online stores with 'consignment services' offer to curate a more targeted product selection; online platforms make it easier to navigate on-screen by selecting by size, brand, colour, type, etc. A change from wading through racks of random clothing in high street vintage stores or charity shops looking for a hidden gem for time strapped working individuals as only items deemed to be stylish, meeting a minimum quality level are uploaded. This takes the risk out of purchasing for a new generation of sustainable and fashion-conscious consumer, often Gen Z ordering online from the comfort of their own home, and outside of high street retailers opening times. It can be argued that the popularisation of a sustainable revolution has been driven as much by a cost-of-living crisis through discounted style, as it is about reducing denim production and the environmental costs. There has also been, "*an explosion in the fast fashion industry* [allowing] *people to update their wardrobes regularly at a modest cost".* (Ritch, 2025). In the luxury sector there has been a reduction in sales in a 'riches to Rags 'situation (Times 20th April, 2025), whilst second-hand luxury is booming at the expense of new, raising the possibility of second-hand denim online sales being phenomenon fuelled by Gen Z and 'the squeezed middle' in the UK (Pithers E, 2022).

Denim take-back schemes

Established brands are implementing take back schemes such as Diesel, where reselling their used brand again as a vintage product introducing curated pre-owned goods publishing the date and name of the design on their website as part of the resale value, (Diesel.com, 2025). Levi jeans advertise and curate pre-owned collections in the US. Both have moved to separate sites, although Levis previously had a pre-owned section on their main site for US customers only, this has recently been removed to a separate site, (Levi's, n.d.) perhaps due to second hand jeans sales affecting new sales or for international sales.

Denim brands offer a range of incentive offers to encourage consumers to return their used denim for recycling or resale. They range from a percentage discount from 10-20% for brands such as Mud and Nudie to a flat fee voucher of £50 from Hiut. Other brands such as Levis and Diesel offer vouchers dependant on the condition and value of the item returned, whilst Gap works with resale platform ThredUp and offers a voucher for a % of the resale list price. Not all the schemes are available in the UK with some just limited to a country or region. In addition to take-back schemes, some brands are offering repair services such as Mud, E.L.V, Hiut, Nudie and Levis. As previously mentioned, some brands retail the returned denim in store or online, via a resale partner such as Thred Up or in the case of E.L.V. Denim, upcycle the returned denim into new jeans or sell through resale platform reskinned. In addition to take back schemes, some brands offer repair services, incorporate organic or recycled fabrics or have leasing programs.

The details of the incentives are summarised in the table below.

Brand	Incentive for take back offered	Reuse	Recycle	Repair	Other
Diesel	Gift voucher of € 15 or € 25 or € 35 offered depending on condition of garment returned.	second-hand Diesel jeans available at selected Italian stores and online. Prices range from £65-£130, regular price for new £145- £500	recycled materials used within the ranges.	n/a	Organic cotton used within the ranges.
E.L.V. Denim	Return an old pair of jeans and receive up to £40.00 voucher off a new pair of jeans	Yes, remade into a new piece	n/a	Lifetime repair offered on their jeans free for small adjustments, chargeable for larger alterations.	n/a
Gap	Get 3-80% of sell price back as voucher for Gap, depending on value of item. Higher value = higher return.	Yes, in the US. Partnership with ThredUp customer can return any brand to ThredUp	n/a	n/a	n/a
Hiut Denim Co	£50 voucher off a new pair of jeans.	Yes, sold online by brand prices range from £100-£150 regular price of new denim £245-£290	n/a	Free repairs offered in UK by brand (consumer pays postage, higher fee if outside of UK)	Organic cotton available in the range
Levis	‘Gift card towards future	Only in US sold online at	Some recycled denim in the range.	Available in ‘tailor shops’	n/a

	purchase offered.' 'trade-in credits range from $5 to $35 based on your item's age, condition and original retail price.'	secondhand.levis.com		upcycling, distressing, embroidery, repair available.	
Mud Jeans	10% discount on a new pair of jeans. Any brand can be returned must be 96% cotton.	n/a	Returned denim mechanically recycled and blended with organic cotton.	Available throughout the Netherlands with partner provider MENDED	Leasing scheme available for monthly fee, after 1 year can keep, replace, or return.
Nudie Jeans	'20% off new denim item'	Yes, sold online and in all repair shops and partners (49 stores globally)	Yes, can include customer returned denim, production waste, fabric suppliers waste.	Free repairs available at 34 Repair shops and 15 partners globally.	Organic cotton available in the range.

ELV Case study

There are reused markets where upcycled denim is refashioned to make new products out of used clothing; these products are marketed as 'atelier' one offs or small runs and are at the high end of the market, for example E.L.V. Denim (East London Vintage).

Influencers can partner with brands for collaborations and sponsored posts, this can happen across various platforms including, Instagram, TikTok, YouTube, video posts or blogs, in promoting specific items. These influencers can generate their own income through earning commission with affiliate marketing schemes and could be partnered with a specific brand. E.L.V. Denim, founded by stylist, Anna Foster in 2018 trade under the mantra, *'We breathe a second life into garments destined for landfill, transforming loss into luxury.',* (ELV Denim, 2025). Posting regular stories to their account, they are aware of the influence and power of social media in the development of their brand. Passionate about over consumption E.L.V. Denim seeks to upcycle denim into relevant and fashionable pieces that breathe new life into a garment, they advertise that they have upcycled 35,000 jeans so far, saving them from landfill, reducing 267million litres of water. Sourced locally from UK vintage wholesale warehouses and remade locally thereby saving on carbon footprint.

They re-tailor the jeans and extract pieces from the reused denim to make new saleable jeans. On visiting E.L.V. Denim and seeing the categorising of used denim first hand, is a skilled knowledge of materials and use, that allow pieces to be sorted specifically for their reuse in production. The remaking of one off upcycled jeans or small runs leads to some waste fabric. Some pieces that cannot be used in the primary designs are made into patchwork any long residue fabric can be used for crocheting bags, minimising waste. Martina Murasso, head of marketing and development at E.L.V. Denim, takes on the responsibility for marketing, the website and the social media posts and has grown its Instagram page to nearly 30k followers, alongside promoting the founder, stylist Anna Foster with a strong narrative in reusing denim. The brand is one of the strongest influencers in used denim in the UK, and they seek out influencers at events to promote their atelier pieces for increased awareness of the brand and message of sustainability, as well as promoting stories in house. E.L.V. Denim have recently promoted a pop-up shop in the centre of London, a temporary space for spring summer to promote sales of their products through events. The events were promoted through stories on their Instagram site.

E.L.V. Denim run a couple of voucher scheme, customers can return a pair of ELV jeans for a voucher or one of the schemes are outsourced to Reskinned, who give customers a voucher on valuing the denim they send to them. ReSkinned and Fabb and (Fabbfashion.co.uk, 2025) present second hand denim as cool, stylish and sharing equally in the status of new clothing. There is also a financial incentive. A pair of second-hand Finisterre jeans on the website 'Reskinned' offers a 50% reduction on that of a new pair (ReSkinned.clothing, 2025).

E.L.V. Denim are at the higher end of the market, with a retail price tag of re-modelled jeans which are high end, individual items re-fashioned into luxury pieces and retail at over £300. They offer lifetime repairs on their products; they make their jeans with enough seam allowance for alterations. One of E.L.V. Denim's unique selling points from customer feedback is the fit of the remade jeans in comfort and tailoring is excellent and builds customer loyalty, Murasso understands this design aspect fundamentally, from a background in couture, the idea of 'atelier' resonates deeply and moving into the marketing side is another aspect of the design process at couture level. They are expanding, shortly they move to new premises to grow production. (ELV Denim, 2025).

The Global North and South debate in sustainable denim

The growth in fashion consumption in Asia, in particular India reflects a growing affluence in the country with some having a higher disposable income. There are 430 million people in India's middle class — greater than the middle classes of the US and Western Europe combined'. (India Brand Equity Foundation, n.d.). This market is consuming predominantly from the non-luxury (fast fashion) segment of the fashion industry (BOF insights, McKinsey & Company, 2024). India is a new market for fast fashion and one which sees the buying of pre-owned clothing as undesirable, reflecting their past, and not the future where wealthy young people in India are able to consume new fashion items often for the first time. India is a young country with 808 million, 66% of the population is under 35 years of age (BOF insights, McKinsey & Company, 2024).

There is an emerging Global South and Global North divide regarding sustainable attitudes towards fast fashion consumption. In the Global North there is an understanding that clothing needs to be more sustainably produced, and this includes recycling of materials as well as a growth in the re use and upselling markets for denim. This is not reflected in the Global South where this level of consumption is reflective of prosperity and wealth and is driven by western influenced fashion trends and social media, (www.coherentmi.com, n.d.).

Rkive City a denim brand in India curates limited denim upcycled ranges for the fashion elite in Delhi and Mumbai (Kamath, 2023). The credentials are well intentioned with an ethos of zero waste. Such brands are raising some awareness of sustainable issues but only to India's educated population that make active choices. The larger impact on denim production is being made by India's growing affluence who equate second-hand clothing with poverty and who want to embrace fashion through affordable fast fashion. (Gzhenrytextile.com, 2025)

Increases in denim production in India has seen a growing requirement for denim producers to be more sustainable in their production. In India manufacturers like Vishal fabrics, who manufacture for Levis, H&M and Tommy Hilfiger, are investing in sustainable production. This includes on site water treatment plants due to the high usage of water in denim production and solar power investment to reduce manufacturing costs. (Indian Textile Journal, 2022) However, "denim brands need to maintain processes where all vendors and customers are operating in an environmentally conscious manner" to ensure that the supply chain has sustainability at each stage of production (Mansur, 2022).

Social media influencers

Social media influencers are known for promoting fast fashion heists, some are now promoting sustainable fashion which have a substantial influence on preloved clothing especially denim on Gen Z. Influencers promote preloved clothing through intelligent storytelling and creating narratives that de-mystify second-hand so that it becomes a fashionable alternative, and a sensible choice in highlighting new markets.

What effect is and can social media have on raising sustainability as a requirement for denim production? Gen Z represent those who are aged 13 to 29 (in 2025). They have an intrinsic relationship with social media. In the UK social media's influence continues to grow w*ith, 54.8 million active users in February 2025 representing 79% of the population* (Dixon, 2025). With such reach it is understandable why new companies curating vintage goods are targeting social media and online stores in preference to traditional bricks and mortar stores. (Rice, 2022)

In February 2025, Tiffanie Darke (@tiffdarke with almost 12k followers on Instagram, 2025) described how, the US are promoting 'No Buy 25', as a no buy challenge and a no spend challenge (prudent in these challenging times of tariffs, high interest rates and increases in national insurance rates in the UK). Social media searches regarding consuming less are, according to Google, up by 40% and has a name 'underconsumption core'; The Rule of Five, a campaign which encourages no buying of new clothes for a year, only buying five new pieces or less. (Chan, 2023). These campaigns are intended to help us to live sustainably and give up fast fashion. (Unfit, Unfair, Resizing Fashion for a Fair Consumption Space Report, 2022). Remaking pieces from used items, Emma Friedlander-Collins (@steelandstich with 46k followers) who upcycles items and promotes how to make them.

The boost in interest in sustainable denim reflects a cohort of social media influencers who are de-mystifying the concept of second hand. They are using impactful influence, where recycled and upcycled products are curated, to explain how selected items can be cool and fashionable to a wide audience of fashion consumers. Social media influencers are developing narratives from fast fashion to sustainable fashion influencer and highlighting that purchasing preowned clothing does not mean 'not being fashionable' building interest through curating preowned collections through their posts. (Kaivonen, 2024). Varg and District.global represent a variety of influencers who promote different areas in the market. Selecting fashion in District.global there were several influencers who content create for fashion, but none were promoted as sustainable influencers, yet.

Fashion influencers often post social media crazes including the 'Fashion Haul' where influencers model items bought from fast fashion brands promoting online and fast fashion purchases to boost their followers (Symington, S 2020). An example @oliviarose currently with 336k followers and has seamlessly moved from H&M heists to children's marketing; she offers a styling service @virtuallystyledby with 283k followers as well as a shopping experience with LTK. Virtually Styled By is a service where customers can request a new wardrobe from as little as £300. The company undertakes detailed research into its clients' needs for a new wardrobe, creating individual look books for those looking for effortless style from across the world. The aim is to keep the client by updating their wardrobes, making seasonal tweaks and updating key pieces. The links to the shop are all through LTK soVirtually Styled By benefits by the commission earned. H&M have partnered with Ellen MacArthur to clean up their denim through projects like The Jeans Redesign and The Fashion ReModel, have ambitions to achieve net zero in the processes by 2040. (Ellen MacArthur Foundation, 2021)

LTK which stands for Like To Know, founded in 2011 by Amber Venz Box a content creator herself, formerly known as rewardStyle. It is an online shop for influencers, accessed by an app where 500,000 content creators can post to LTK their narrative marketing and have relationships with over 7,000 retailers and over 1m brands. They have a reach into 140 countries worldwide; influencers achieving commission on their sales and reaching $4 billion in annual sales with 40 million per monthly shoppers. As an influencer marketing company, it boasts end to end campaign execution, data driven sales through content creation, expert brand consulting with measurable results. (company.shopltk.com, n.d.). Shopify (currently $5.2 billion annually), Fanjoy all have content creator marketing promoted through Instagram usually through Linktree. (Top 100 Creator Economy Companies 2022 NeoReach Report, 2022). At the other end of the influencer spectrum, would be influencers on TikTok market bundles of clothing, Y2K denim jorts, in style bundles for a few pounds. By 2030, the predicted creator economy market is expected to surpass $525 billion annual revenue with US has the most market share at 40%. (Kasplo: All-in-One Marketing Automation & Retention Platform for Businesses, 2025)

The rise of ultra-fast fashion brands including Shein and Bershka which are introducing new items daily, Shein generally 2,000 items a day, (Curry, 2025). In 2022 Shein introduced 315,000 new items during the year and have also introduced Shein exchange to enter the pre-owned market, perhaps to lay down pseudo sustainable routes? (NIQ, 2023)

The challenges of shifting markets

Selling second hand should be profitable as there is no material and manufacturing costs, but there are "difficult economics of processing old clothes for resale" (Wicker, 2024) including sourcing where UK companies have been going out of business due to the high labour cost involved and an oversupply of nearly new clothing fuelled by rise of ultra-fast, ultra-cheap fashion brands, the volume of clothing produced and shipped globally continues to explode, and consumers are offloading more of it after just a few wears. (Wicker, 2024).

Although voucher schemes tempt consumers to engage with the circular economy it can have the reverse effect. (Stal and Jansson, 2017) argue that voucher incentives for take back schemes encourage consumers to empty their wardrobes which could then be filled up again with new purchases. Vouchers offered are redeemed against new purchases consequently encouraging consumption of new rather than second-hand.

Consumers are incentivised by vouchers and discounts to return used clothing to brands for recycling or resale but what are brands motivated by? According to Sandberg et al. (2018) brands strive for 'a zero-sum game.' Aiming where possible not to make profit from take-back schemes. The costs are taken on by partner organisations and any surplus can be donated to charities. Brands work in this way to 'avoid suspicions of being engaged in take-back schemes for profit making reasons.' Instead, retailers benefit from other value such as improved customer loyalty from an enhanced sustainability image. There is also environmental value through reuse (Sandberg et al. 2018).

Awareness of reuse business models is a challenge 'Regardless of the product, the final decision to dispose of an article of clothing and the choice of disposal channel remains the choice of the consumer.' (Weber, et al., 2017). Although consumers are more aware of circular business models such as reuse, they are still not engaging all consumers. According to WRAP the 'pre-loved' business model was the most widely used compared to repair, upcycle, subscription and rental but still only at 19% and 60% had not heard/seen this before (WRAP 2022). Therefore, UK brands still need to work on marketing this new business model if it's to truly impact on sustainability.

The future of denim manufacture needs to embrace efficiency and minimise over consumption of the earth's resources. The challenge of all clothing companies should be to reduce and not overproduce. With over six generation's worth of clothing in circulation, these are the real challenges to get over our obsession with new (Blanchard, 2023).

Conclusion

WRAP TEXTILES 2030, renamed UK Textiles Pact, as there is regulation in EU with Extended Producer Responsibility (EPR), which makes the producer financially responsible for the end-of-life textile products. This means that producers will need to contribute to collecting, sorting, recycling and disposing of textiles and textile waste in the EU. There is no legislation in place currently in the UK which is similar to the EPR in the EU. When research was carried out AHRC UKRI funded Sustainable Materials in the Creative Industries in the UK (Oakley et al., 2021), many in the fashion industries in the UK said they would not change their practice unless legislation was in place. The fact that there are still no regulations for textiles going through parliament despite much lobbying from organisations such as the Textiles Recycling Association and the UK Fashion and Textiles Association to try to get regulation on the agenda, there is a danger that nothing will change quickly.

Change is uncertain and expensive, for one company to invest in resources in recycling is very expensive when collaborating with others can save costs. Where companies work together to achieve recycling ambitions change can be achieved through co-operation. (Oakley et al., 2021). This allows for scale and consistency in operations despite little or no regulation. There is a learning process from all sides and long-term progress can be made, so that it becomes more than placating consumers in sustainability but becomes real change in processes. There needs to be a wider audience through commercial initiatives, without that the only customers choosing more ethical alternatives are from either an educated background or have no choice through economics, that is why legislation in the UK would benefit more consumers and manufacturers and would be more effective. Influencers could do a lot more to help as promoted by UN, but how many influencers refer to the playback book for Fashion Communication, although an excellent tool for education for young graduates, those working as independent content creators would not necessarily be aware of it. (www.unep.org, 2023). Speaking with E.L.V. Denim they are passionate about communicating their sustainable narratives. There is still a vast amount of greenwashing in the retail industry negating the work of sustainable practice, it is a minefield telling the consumer white lies which will not build long term trust. Traceability of supply is vital in textiles but is being hampered by fake labels indicating that textiles is real when it's not. OEKO-TEX is certified with a certification number and with the rules and guidelines that govern its use. (Oeko-tex.com, 2025)

The Global South will need to change their approach, they are slowly progressing, (Connecting for Positive Change _ ktn-uk.org/Global Global Expert Mission Sustainable Fashion in India, 2021) and Safia Minney MBE from Fashion Declares! is working closely with small companies in India to promote sustainable practices especially in cotton. (Bureau, 2025). Educating manufacturers as well as consumers in the Global South is a multi-pronged effort, all of us need to make.(Wohlgemuth, 2022). As Fashion Declares! Tries to launch a White Paper (Marcus 2025), it is ironic that regulation may come quicker in the Global South than in the UK.

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The Cultural Barriers to Sustainable Innovation within Organisations

Ari Hautaniemi

RDI Specialist

LAB University of Applied Sciences

Finland

Abstract

This conceptual paper investigates how deeply rooted organisational cultures and subcultures can hinder sustainability transitions. Drawing on Schein's model of culture and theories of organisational identity, it argues that misalignments between sustainability objectives and deeply ingrained norms can foster hidden resistance, even when strategic intentions are clearly defined.

The paper offers three scenario-based thought experiments that illustrate symbolic compliance, subcultural friction, and identity conflicts within organisations committed to sustainability.

It highlights the importance of participatory sense-making, narrative reframing, and decentralised experimentation for achieving cultural alignment. Recommendations include engaging subcultures in defining sustainability, training internal facilitators to bridge cultural divides, and recognising emotional responses to change. The paper concludes that successful sustainability transformations involve significant cultural efforts prioritising identity, emotion, and meaning.

Introduction

With the acceleration of climate change, resource scarcity, and evolving regulations, businesses face increased pressure to align their operations with sustainability principles. The United Nations Global Compact (UNGC 2018) encourages companies to integrate human rights, labour, environmental, and anti-corruption principles into their practices. The European Commission (2020) has also initiated programs to promote sustainable innovation, emphasizing the need for technical adaptations and organizational transformation. Strategies like the circular economy, eco-design, and low-carbon innovations have become essential for long-term competitiveness and regulatory compliance (Geissdoerfer et al. 2017; Kirchherr et al. 2018; Kiron et al. 2017; KPMG 2017).

However, sustainability transformations often create tensions among economic, environmental, and social objectives. As van der Byl and Slawinski (2015) point out, navigating these tensions is complex, requiring understanding cultural frameworks that shape organisational responses. Alvesson and Sveningsson (2015) highlight that change is more than altering structures or adopting new methods; successful initiatives must consider organizational culture to avoid failure or unintended consequences.

Sustainability initiatives may falter due to clashes with long-standing cultural norms and values, which can resist or dilute formal policies (Schein 2010; Howard-Grenville 2020). If cultural foundations are misaligned with sustainability goals, organizations may experience hidden bottlenecks and resistance, leading to a gap between strategic ambitions and operational reality (Boiral 2007).

This conceptual paper examines these dynamics through the lens of organizational culture theory, exploring how implicit norms and subcultures affect sustainability transitions in business models and innovation. It provides hypothetical scenarios to illustrate typical resistance patterns, offering insights for practitioners and researchers striving to integrate sustainability into organizational strategy and culture.

Organisational culture, identity and dynamics of change

"Culture isn't just one aspect of the game; it is the game." Louis V. Gerstner Jr., IBM.

Organisational culture is a complex social system that shapes decision-making, communication, and change processes. It consists of shared meanings, norms, and routines that influence members' understanding of their roles. Organisational psychologist Edgar Schein's layered model categories culture into artefacts (visible practices, e.g., explicit strategies, annual reports, dress codes and office layouts), espoused values, and, at its core, the basic underlying assumptions (unspoken, unchallenged truths). The deepest level, underlying assumptions, dictates what is deemed rational or desirable and often shapes behaviour unconsciously. These assumptions have evolved over time into a default cognitive map for encountering external and intra-organisational issues (Schein, 2010; Hofstede et al. 1990).

Schein (2010) states that understanding culture is imperative when initiating change. This comprehension cannot be gained by examining the superficial layers and artefacts that make little sense to someone outside the organisation if not viewed through analysing the underlying layers. Social psychologists Lee Ross and Andrew Ward (1996) coined the term 'naïve realism' to refer to the false assumption that our subjective experience directly reflects objective reality: we see things as they truly are, without any distortion from our senses or individual perspective, and expect anyone else to perceive it the same way. To escape the bias of naïve realism and to fully understand why people do what they do and say what they say requires one to delve into the deeper levels of culture that expose the hidden values, beliefs, norms and cognitive patterns that govern behaviour (Schein 2010).

Subcultures and the Dynamics of Change

Culture is rarely uniform but includes various subcultures that align with specific groups or departments. These subcultures can drive innovation but may also cause fragmentation or resistance to central strategies. Thus, shifting organisational behaviour towards sustainability relies on strategic intentions and the cultural resonance of these new priorities.

A strong, integrated organisational culture can enhance performance and employee satisfaction (Yılmaz & Ergün 2008; Laforet 2016). In large corporations, various subcultures may emerge within departments or teams, aligning with or diverging from the dominant culture (Van Maanen & Barley 1984; Martin 2002). For instance, a product development team may prioritise sustainability, while the finance department focuses on risk aversion and cost-cutting. Such cultural misalignments can create friction and hinder innovation, particularly when collaboration is essential for sustainability initiatives.

Subcultures can provide adaptability and knowledge specialisation but may also complicate the implementation of sustainability strategies due to conflicting cultural logic (Lok et al. 2005). If sustainability goals are communicated only through managerial discourse, they may seem inauthentic or irrelevant to frontline employees (Howard-Grenville, 2006; Carlström & Olsson, 2014). In organisations facing constant change, countercultures can emerge, increasing resistance to official agendas (Mello & Schloemer, 2022).

Research indicates that subcultures often persist even after restructuring efforts, demonstrating the resilience of cultural boundaries (Egan, 2008; Mello & Schloemer, 2022). Effective sustainability transformations must, therefore, address not only structural and strategic elements but also the cultural frameworks that influence behaviour.

While formal strategies guide organisational actions, unspoken norms, "the way things are done here", significantly impact daily decision-making (Martin, 2002; Feldman & Pentland, 2003). In sustainability contexts, these implicit norms can undermine green initiatives if they conflict with dominant priorities. For example, even if a company promotes circular design, a norm favouring short-term financial performance can lead to quiet employee resistance to new practices, often reinforced by peer behaviours and managerial expectations.

Culture and Identity: Interconnected Constructs

Organisational identity, its core character, is closely linked to culture. It is the answer to the question "who we are,". Culture comprises the assumptions that support this identity (Schein 2010). Schultz and Hatch (2003) highlight that identity is shaped through the interaction of internal culture, external perception, and branding. Cultural elements stabilise identity, especially during transformations. When identity is under threat, whether real or perceived, protecting it becomes imperative, overriding any other agendas and resulting in counterproductive behaviours (Yashika & Prakash 2024).

Ravasi and Schultz (2006) note that the cultural interpretation of external pressures affects how identity threats are managed. Ogbonna and Wilkinson (2003) found that middle managers might resist cultural changes not just because of their values but also because of the impact on their narratives of identity and competence. Therefore, sustainability initiatives can be perceived as challenges to identity, risking rejection if they conflict with the organisation's self-concept.

Within a company, identification can be strong towards one's significant subculture, not necessarily the entire corporation, influencing the norms and values that govern action and thought.

Sustainability as Cultural Transformation

Many organisations now view sustainability as a strategic priority, but effectively implementing it requires significant cultural change. Studies indicate that meaningful progress in sustainability goes beyond technical solutions and compliance; it necessitates a shift in values and what is celebrated within the organisation (Boiral 2007; Giacomelli et al., 2024). This involves redefining success, reassessing resource consumption, and challenging routines that conflict with ecological principles.

True transformation should engage with the organisation's cultural logic and identity rather than remaining superficial or isolated. Without this, sustainability may become a mere management claim without impacting daily practices. Organisational culture and identity are crucial in shaping the credibility and implementation of sustainability strategies.

Evidence from Nureen et al. (2023) shows that sustainability initiatives thrive when embedded in the culture and co-created with employees. Key factors include leadership modelling, open communication, and participatory engagement, which help align sustainability goals with organisational identity and address resistance linked to existing practices and values.

Methodology

This paper employs a conceptual, scenario-based approach to examine how entrenched organizational cultures and subcultures can obstruct the effective implementation of sustainability strategies. Instead of using empirical data, it creates hypothetical scenarios informed by scholarly insights on organizational culture, identity, and change. These scenarios serve as tools for reflection and theorizing potential challenges and interventions in culturally rigid organizations. (Hirschheim 2008.)

Following Jaakkola (2020), the study integrates perspectives from various theoretical frameworks, including organizational culture theory (Schein 2010), subcultural differentiation (Hofstede 1998; Howard-Grenville 2006), and organizational identity (Gioia et al. 2000), to conceptualize resistance to sustainability as a cultural phenomenon. The theories are reviewed descriptively and utilized to construct a coherent argument.

Drawing on Ramirez et al. (2015) and Ramirez and Ravetz (2011), the scenario method focuses on strategic foresight rather than predicting outcomes. It highlights how specific cultural dynamics may hinder sustainability efforts. Each scenario is logically structured to show how organizational values, norms, and identities can support or impede these initiatives.

These scenarios are framed as thought experiments, not empirical findings, to enhance our understanding of cultural and identity-based barriers to sustainability. The paper concludes by offering strategies to recognize and address these challenges, advancing insights into the requirements for sustainable transformation beyond formal strategies

Scenarios

Scenario 1: The Sustainability Manager with No Followers

This scenario highlights how sustainability efforts can devolve into mere tokenism when not deeply ingrained in the organisational culture. A mid-sized industrial engineering firm with a history spanning over 80 years proudly announces a commitment to sustainable production as part of its decarbonisation roadmap. The CEO confidently claims, "We will become a leader in low-carbon manufacturing within five years," the initial response is encouraging.

However, as the sustainability planning gets underway, department heads and senior engineers begin to reinterpret these ambitious goals to fit their established values of precision and cost efficiency. As Schein points out, fundamental assumptions remain unchallenged. Sustainability is downplayed, becoming just another tool for improving efficiency, and in the process, it loses its ecological importance.

While employees generally support sustainability targets, their daily routines are shaped by old key performance indicators (KPIs), emphasising predictability. There is no outright resistance, but the momentum for change is noticeably lacking. This aligns with Howard-Grenville's findings that subcultures tend to adapt external requirements into familiar stories, which can diminish their transformative potential.

Although the company achieves some moderate success in cutting down waste and energy use, it struggles to shift toward circular business models that would necessitate rethinking product lifecycles. The firm's identity as a cautious, orderly institution remains intact, underscoring the challenges of navigating sustainability transitions in organisations with rigid cultural frameworks.

Scenario 2: The Subculture That Resisted

This case highlights subcultural resistance, where established identities clash with new environmental initiatives. Howard-Grenville (2006; 2010), Ogbonna and Wilkinson (2003) and Yashika and Prakash (2024) explain that such resistance arises from historical identity frameworks that create a perceived misalignment with company strategies.

In this scenario, a tech scale-up specialising in cloud-based logistics rolls out an ambitious sustainability plan to reduce its digital carbon footprint, ethically source hardware, and ensure transparency in AI practices. However, the sustainability team encounters significant pushback shortly after the initiative is launched. Product developers question the importance of emissions tracking, while DevOps teams label the plan as just "another compliance wave." Senior developers express concern that these sustainability efforts might impede their pace and ability to innovate.

This response highlights the gap between leadership's vision of ethical responsibility and the prevailing culture of rapid innovation. The green agenda is viewed as a contradiction to what defines the company's success from the perspective of its technical staff. As a result, sustainability reports are generated with minimal input from engineering and product teams. While employees may seem compliant, actual changes in workflows remain limited, underscoring findings by Ogbonna and Wilkinson (2003) regarding resistance to identity-threatening shifts.

The scenario illustrates how a disconnect between managerial discourse and subcultural identity can lead to mere performative compliance, emphasising the need for sustainability leaders to align their strategies with the cultural values of key internal groups.

Scenario 3: The Participatory Turn

This scenario highlights the vital role of participatory change processes in aligning an organisation’s identity and culture with sustainability strategies. By empowering subcultural actors, they can take ownership and integrate new values through collaborative efforts.

Within a multinational conglomerate that spans consumer electronics, retail logistics, and bio-based packaging, a centralised sustainability strategy exists to achieve carbon neutrality and circular sourcing. Although this strategy is well-documented and broadly supported, the progress varies significantly across divisions. The electronics unit easily adopts the plan, while the logistics division raises doubts about the feasibility of these goals due to stringent delivery schedules. Conversely, driven by a strong local commitment to environmental issues, the packaging division often pursues parallel initiatives that sometimes diverge from corporate guidelines.

These discrepancies reveal cultural differences that go beyond mere operational challenges. Subcultures, shaped by professional and regional distinctions, influence how sustainability is interpreted and acted upon. The conglomerate struggles with a cohesive identity, facing competing priorities of compliance, innovation, and stewardship across its units.

As coordination falters due to this “identity fragmentation,” confusion emerges, leading to a disconnect between the overarching strategy and local circumstances. Employees may become cynical, perceiving the sustainability efforts as inconsistent. This scenario underscores the importance of addressing subcultural identities to ensure that sustainability strategies are effectively implemented.

Conclusions and Practical Recommendations

These scenarios illustrate that cultural change in pursuit of sustainability is not only about strategy, but about reconfiguring meanings, practices, and identities within organizations. In the next chapter, this paper offers prescriptive reflections on how sustainability advocates might more effectively engage with the cultural realities of organizational life.

As sustainability efforts continue to proliferate across industries, the gap between strategic intent and organizational reality remains a critical bottleneck. This paper has argued that such friction often emerges not from poor planning or lack of vision, but from cultural misalignment where new sustainability agendas are introduced without adequate attention to the values, identities, and everyday practices that already shape organizational life. Through the lens of Edgar Schein’s model of organizational culture and insights from organizational identity theory, we have shown how these tensions manifest in real and symbolic resistance, selective interpretation, and subcultural friction.

Practical Recommendations

The scenario-based illustrations offered in this paper are not empirical case studies but conceptual tools designed to expose how sustainability initiatives might be reframed or resisted due to deeply embedded cultural assumptions. They highlight the need to think beyond strategy and structure and treat culture and identity as co-determinants of success or failure in sustainability transitions.

Organisational change is most sustainable when it is co-created. Rather than introducing sustainability as a finalised agenda, leaders should foster participatory processes where employees across functions and levels can contribute to shaping what sustainability means in their specific context. Participatory sense-making enhances legitimacy, increases engagement, and allows local interpretations to emerge that align with the organisation's broader goals (Schein, 2010; Nureen et al., 2021).

Leadership must shift from managing performance to curating meaning. Leaders who model sustainable behaviour in ways that resonate with their organisation's cultural fabric can act as sense-givers who make sustainability intelligible and credible (Schein, 2010; Ravasi & Schultz, 2006). This includes aligning stories, symbols, rituals, and metrics with environmental values, not just issuing new directives.

Sustainability initiatives often clash with established professional or departmental identities. Instead of marginalising these identities, leaders and change agents should seek to bridge them through narrative reframing and identity work. Helping individuals and subgroups see their professional values reflected in sustainability goals enables integration rather than alienation (Gioia et al., 2000; Schultz & Hatch, 2003). Sustainable, lasting change in thought and action is not about the strength of the efforts of the one trying to change someone’s mind. It is about initiating and supporting the cognitive process taking place within the individual through respect, honesty and empathy. (McRaney 2022.)

Organisations should invest in training internal facilitators, such as middle managers and staff peers, to communicate strategy and interpret and translate it in culturally meaningful ways. Recognising subcultural nuances and avoiding one-size-fits-all communication fosters trust and reduces symbolic compliance.

Change initiatives benefit from decentralised experimentation. Rather than enforcing strict top-down programs, organisations can encourage teams to prototype sustainability practices locally that align with their cultural norms and then share those practices through internal networks. This strengthens cultural coherence while allowing for adaptive fit.

Finally, leaders should be acceptive of sense of uncertainty, pride, belonging, fear, and the full emotional scale that comes along with anything that challenges the status quo. As Jim Goodnight, the CEO of the statistical analytics software SAS, has put it, "Treat employees like they make a difference, and they will" (Press 2017).

Limitations and Future Implications

This paper is conceptual and lacks empirical data, limiting the generalizability of its insights. The hypothetical scenarios simplify complex cultural dynamics and may not reflect variations across different industries, national contexts, or organizational sizes. It primarily focuses on internal organizational actors, neglecting the influence of external stakeholders like regulators or customers. Additionally, without quantitative measures, the practical impact of the proposed approaches remains unassessed, indicating a need for further empirical investigation.

Future research could enhance this conceptual framework through in-depth qualitative studies, such as ethnographies, to explore cultural interpretations of sustainability strategies in various settings. Investigating how employees adapt their professional identities in response to ecological imperatives and conducting longitudinal studies on identity evolution during sustainability transitions are also recommended. More attention should be given to the role of leaders as cultural translators in politically sensitive or resource-limited environments. Applied research could develop participatory methods that embed sustainability into identity and cultural alignment processes.

Schein (2010) notes that effective organizational change requires addressing foundational cultural assumptions. Cultural transformation involves reshaping the shared meanings and assumptions within an organization. Strategies that overlook informal dynamics may face resistance, while those that engage with cultural logic and leverage allies are more likely to foster lasting change. Thus, culture should be approached as a system to engage with, promoting humility, creativity, and shared ownership.

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Co-Designing Transparency: Understanding Barriers and Opportunities in the Transition Toward a Transparent Shipbreaking Industry

Maria Marilyn Joseph

PhD Candidate

Royal College of Art

United Kingdom

Dr. Alessio Franconi

Senior Tutor

Design Futures

Royal College of Art

United Kingdom

Dr. Elise Hodson Academic Lead

MDes Design Futures

Royal College of Art

United Kingdom

Abstract

Shipbreaking is the process of dismantling obsolete vessels to recover valuable components. While the industry supports local economies, it raises serious concerns around hazardous waste, poor regulatory enforcement, and worker safety. The Hong Kong Convention (HKC), set to take effect in 2025, marks a turning point for global ship recycling standards.

This paper explores how futures studies and design methodologies can support a transparent and sustainable transition in shipbreaking. A mixed-methods approach, combining systems mapping, stakeholder interviews, empathy mapping, and backcasting, was used to identify critical transparency gaps, particularly in hazardous material documentation and inconsistent regulatory oversight across yards (Maritime India, 2023).

The study proposes *Blue Vigil*, a speculative blockchain-based system for Digital Product Passports (DPPs) and decentralized documentation. It highlights targeted benefits for shipbreaking yards, shipowners, State and NGOs, while presenting a roadmap of political, technological, and social actions. Ultimately, it positions design as a strategic tool to envision and enable a more ethical ship recycling future.

Introduction

Before the 1960s, ship breaking was carried out mainly in the United States and parts of Europe IMO, 2023). As labour and environmental costs rose, the activity migrated to lower-cost regions, first to Turkey and, by the 1980s, to South Asia. Today, India, Bangladesh, China, Pakistan and Türkiye dominate the sector (Secretariat of the Basel Convention, 2003; NGO Shipbreaking Platform, 2024) and it plays a critical role in Maritime Sustainability. As a major economic driver in South Asia, particularly for local steel industries, In Bangladesh alone the sector supplies 60% of domestic steel and employs over 40,000 people. (NGO Shipbreaking Platform, 2024) Salvaged materials from steel to furniture and machinery fuel thriving second-hand markets. Recycled steel significantly lowers greenhouse gas (GHG) emissions compared to virgin ore, aligning ship recycling with circular economy principles (Franconi et al, 2022).

Ecological Impact and Labour Safety Concerns

The ecological consequences are profound. Dismantling on open beaches leads to runoff of oil, heavy metals, and other toxins into coastal waters, threatening marine biodiversity. Acidic gases, rust particles, and carcinogens further affect air and soil quality. (Sejan, Mahfuz, and Urmi, 2024). The longterm health exposure to people workingWhile the industry reduces the need for mining virgin materials, mishandling of toxic components like asbestos, PCBs, and oil residues contaminates the local ecosystem and exposes labour to unsafe working environments (ECORYS (2005); NGO Shipbreaking Platform, 2024).

Regulatory Landscape and Systemic Challenges

International bodies such as the IMO, ILO, EU, and NGOs, including IndustriALL Global Union, have expressed concerns about hazardous waste management and worker safety (IMO, 2023; European Commission, 2023; Greenpeace, 2022). The Hong Kong International Convention (HKC), entering into force in 2025, sets global standards for the environmentally sound recycling of ships. Countries like India, Bangladesh, and Türkiye, three of the five nations where most ship recycling takes place, are now parties to the HKC. (IMO, 2023; NGO Shipbreaking Platform, 2024). At the national level, India, Bangladesh, and Pakistan have implemented shipbreaking regulations aligned with HKC principles, including India's *Recycling of Ships Act* (2019), Bangladesh's *Ship Breaking and Ship Recycling Rules* (2011), and Pakistan's *Balochistan Ship Breaking Industry Rules* (1979). The HKC mandates authorized ship recycling facilities to implement a Ship Recycling Facility Plan addressing worker safety, environmental protection, emergency preparedness, and record-keeping per IMO guidelines. (IMO, 2023). Ships must carry a verified Inventory of Hazardous Materials (IHM). Compliance with the HKC will be especially consequential for high-volume yards such as Alang, India (Sejan, Mahfuz & Urmi, 2024). While the HKC aims to promote uniformity across ship recycling practices, scholars have pointed out its limited enforceability and reliance on national capacity-building, which can lead to significant disparities in implementation across the Global South (Rousmaniere and Raj, 2020). IMO is working with recycling countries to help build the capacity and establish the conditions that will enable them to ratify/accede to the Hong Kong Convention. It is a complex issue, often involving many different ministries and industry groups. (IMO, 2023).

The European Union Ship Recycling Regulation (EUSRR) restricts EU-flagged ships to approved facilities to promote safer recycling (European Commission, 2023). However, critics highlight loopholes like re-flagging and weak enforcement that undermine its effectiveness (Witte, 2024; Piet & Betz, 2024).

Background and Literature Gap

Despite rich scholarship on ship-breaking's labour precarity, material flows, and regulatory failures, the literature remains fragmented: human-geography and labour studies expose informal working conditions (Rousmaniere & Raj, 2007; NGO Shipbreaking Platform, n.d.), Other studies analyse the global value chains that link end-of-life vessels to secondary markets, showing how materials like steel and equipment are repurposed through largely undocumented material flows. These material flows rely not on rigorous scientific measurement but on rough weight estimates and expert judgment. (Jain, Pruyn and Hopman, 2015), and Environmental policy scholars have also highlighted the challenge of identifying and managing hazardous materials (Ülkü and Hsuan, 2024) while urging locally rooted governance (Kurtz, 2017). What is still missing is an integrative framework that links these strands to actionable transition pathways, one that (i) maps the socio-technical systems, (ii) grounds insights in multi-stakeholder perspectives, and (iii) tests future-oriented design scenarios for circular and just outcomes. The present study addresses this gap by combining systems mapping, stakeholder analysis, and speculative design to reveal leverage points and prototype interventions.

Research Aims and Methodology

Objectives

The objectives of this paper include identifying systemic inefficiencies that negatively contribute to building transparency in shipbreaking practices, using Alang as a case study. The following questions frame the inquiry

What are the systemic barriers preventing transparency and circularity in shipbreaking

How might we promote a just and sustainable transition in ship-breaking practices, through enabling transparency in material flow, enhancing stakeholder engagement, and compliance monitoring?

Methodology This study adopts a design-led, systems-oriented approach combining qualitative and speculative research tools.

Literature and policy review of the existing frameworks, such as HKC, to understand their socio-material implications in regions like Alang. (IMO, 2023; Sejan, Mahfuz, and Urmi, 2024). Several maps were created to support the analysis, including current and proposed material flow maps, a stakeholder interaction system map, and comparative system maps from related industries such as green hydrogen. These visual tools helped identify cross-sectoral intervention points.

Seventeen semi-structured interviews were conducted with shipbreaking yard managers, local regulators, NGO representatives, and shipping industry stakeholders. Interviews were transcribed and analysed using thematic analysis, where codes were inductively derived and grouped into themes addressing the barriers to transparency.

Empathy mapping was used to incorporate the lived experiences of labourers and community members.

Trend analysis identified socio-technical drivers such as automation, material traceability, and digital documentation.

Backcasting In this phase, a preferable future scenario was defined, and then critical pathways and enabling conditions were traced back to the present.

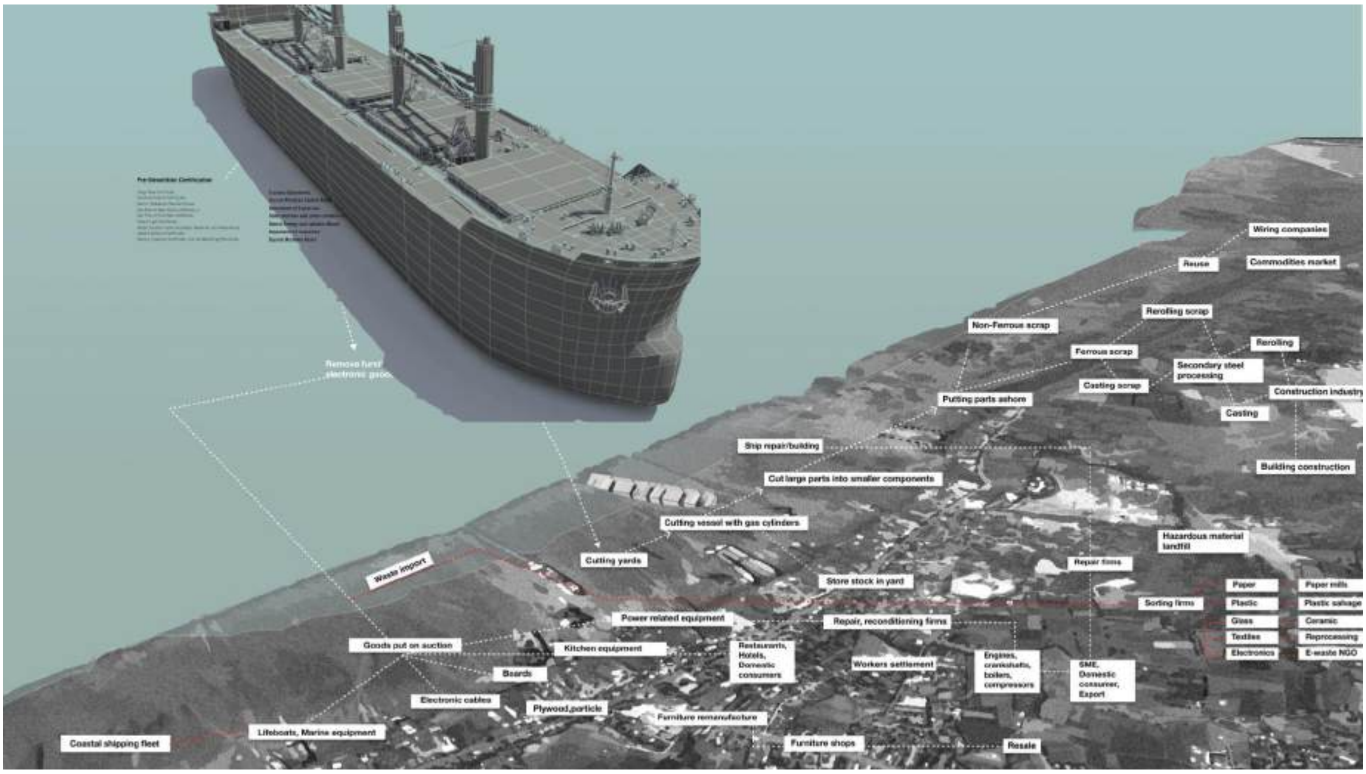

Figure 1: Material Flow Map of the Shipbreaking System in Alang, India.

Systems and Stakeholder Mapping

Seventeen semi-structured interviews were conducted across India, Switzerland, and the UK to map the shipbreaking system, identify transparency barriers, and understand stakeholder interdependencies. Interviewees included technical and compliance managers from shipping companies like MSC and Maersk, offering insights into recycling decisions and the challenges of implementing responsible ship recycling practices. A shipbreaking yard owner in Alang discussed on-ground documentation and compliance challenges, while a technology consultant shared perspectives on digital traceability solutions.

Policy-level insights came from representatives of NGOs and industry bodies such as the Ship Recycling Transparency Initiative, IndustriALL Global Union, and GSR Services, who emphasized accountability and the need for accurate documentation and accountability across the system. The informal sector was represented by members of the Self Employed Women's Association (SEWA), who highlighted women's experiences in sorting and repurposing ship materials in secondary markets.

Insights from these diverse actors informed the development of a system map (Figure 1), illustrating material flows and stakeholder roles. This mapping revealed inefficiencies in documentation and information-sharing, identifying possible intervention areas.

Key Findings

While the shipbreaking industry faces a wide array of systemic challenges, including poor worker protections, informal labour practices, inadequate infrastructure, weak market incentives for traceable materials, technological limitations, and global power asymmetries, this paper focuses specifically on those barriers that most directly impact transparency and traceability.

Barriers

Enforcement of ship recycling regulations

While international frameworks such as the HKC set baseline standards, these are not uniformly implemented or enforced (IMO, 2023). Ships often evade oversight by changing flags shortly before dismantling, a tactic known as *re-flagging,* or by transferring ownership to intermediary companies in jurisdictions with weak compliance requirements (Witte, 2024). As a result, even ships originating from countries with strict regulations can be dismantled in substandard facilities. Port authorities and flag states often lack the resources or political will to monitor vessel trajectories, enabling shipbreaking yards to operate in regulatory grey zones, particularly in India, Bangladesh, and Pakistan (Piet and Betz, 2024).

Fragmented and Inaccessible Data Flows

Documentation across the shipbreaking lifecycle, especially concerning hazardous materials, is often fragmented, inconsistent, and inaccessible to relevant stakeholders. Inventories of Hazardous Materials (IHMs) and Pre-Demolition Certificates (PDCs) are frequently paper-based, vary in format between shipowners and countries, and are rarely updated or standardised across ports, flag states, and shipyards (European Commission, 2023). In practice, compliance teams at shipyards rely heavily on technical assumptions, previous knowledge of likely contaminated zones, and selective lab testing. Since large-scale testing of components is expensive and time-consuming, many hazardous materials go undetected or are mishandled during dismantling. Key information, such as a component's material composition, repair history, or date of last inspection, is often missing, outdated, or never transferred during vessel handover. This breakdown in data continuity severely limits traceability and undermines the enforcement of international safety and environmental standards (Gregson et al., 2010; Crang et al., 2013).

Economic and infrastructural constraints

Many ship recycling yards, particularly smaller or independently run facilities, operate on narrow profit margins and are embedded in informal economies. The cost of adopting digital tools, hiring trained compliance officers, or upgrading documentation systems can be prohibitively high (European Commission, 2018, p. 22). Even when incentives exist, smaller yards may lack the technical infrastructure or regulatory support to meet international compliance standards. Moreover, downstream buyers such as scrap dealers and secondary materials markets often do not demand traceable or certified components, reducing pressure on yards to invest in transparency-enhancing technologies. Without aligned economic incentives and adequate institutional support, many actors continue to prioritise cost-saving over compliance, further entrenching the sector's opacity (Shipbreaking Platform, 2024). These gaps fundamentally undermine efforts to ensure transparency and accountability across the industry.

Opportunities

The following opportunities are structured as direct responses to the key barriers identified above

Digital Product Passports

To address fragmented and inconsistent data flows, Digital Product Passports (DPPs) offer a structured approach to recording and accessing a vessel's material composition, maintenance records, and ownership history. These passports systematically document critical data across the vessel's lifecycle, ensuring that essential information, such as hazardous material inventories is consistently available at each stage. By standardizing data capture and improving data continuity, DPPs reduce reliance on assumptions or selective lab testing, directly responding to the transparency issues outlined in previous section.

Decentralised Ledger-Based Bookkeeping

In response to the challenge of regulatory evasion and poor oversight, decentralized ledger-based bookkeeping introduces tamper-resistant, transparent systems that record transactions and compliance activities across stakeholders. These ledgers can serve as a shared, immutable source of truth, making it difficult for actors to manipulate documentation (e.g., re-flagging or last-minute ownership changes). Regulators, shipowners, and dismantling yards can all access the same live data streams, which enhances accountability and enables real-time compliance monitoring an effective countermeasure against regulatory grey zones.

Cross-Cultural Knowledge Exchange and Frugal Innovation

Frugal innovation, or 'jugaad,' offers the potential for locally adapted, low-cost tools for reusing ship components providing practical alternatives to complex and expensive infrastructure. In shipbreaking yards with limited resources, such as Alang or Gadani, these low-cost, resourceful solutions grounded in everyday practices can help bridge digital and economic gaps. Cross-cultural knowledge exchange between NGOs, government agencies, and industry stakeholders can support the sharing of best practices while building the institutional trust necessary for meaningful transition. This is particularly important for improving the perception of yards undergoing reform by showcasing grounded realities. Crucially, recognising and building upon existing informal practices rather than displacing them is essential when applying circular economy strategies in transitional ship recycling contexts.

Blue Vigil: Speculative system proposal

Blue Vigil is a speculative design proposal to address some of the industry's transparency challenges. It is a prototype of a system, based on blockchain technology for digital product passports (DPP) and decentralised record-keeping software designed specifically for the ship-breaking industry.

Platform Architecture

Based on the findings, a proposal was developed to test ideas about a blockchain-enabled digital platform that introduces Digital Product Passports (DPPs) for end-of-life vessels. These passports would contain verifiable data on materials, certifications (e.g., IHMs, PDCs), and real-time dismantling activities. This data-driven infrastructure links multiple stakeholders via shared ledgers to ensure traceability, secure record-keeping, and efficient policy compliance. An overview of the two core sections is shown below (Figure 2).

Figure 2: Blue Vigil Platform overview

Core Functions

Material Tracking: End-to-end visibility of steel, hazardous waste, and equipment.

Integrated Bookkeeping: Secure upload of documents like demolition certificates, safety logs, and auction data.

Auction Interface: Marketplace for verified, traceable resale of dismantled components.

Compliance Monitoring: Live dashboards for regulators to flag non-compliance in real time

Analytics for Policymakers: Trends in dismantling activity, violations, and materials recovery.

Stakeholder Benefits

The following section outlines stakeholder-specific benefits of the proposed Blue Vigil system, with accompanying illustrations that depict tailored platform interfaces and how each supports the stakeholder's unique needs within the shipbreaking ecosystem.

Regulators and international agencies gain better tracking of Inventories of Hazardous Materials (IHMs) and Pre-Demolition Certificates (PDCs), supporting auditing, enforcement under the Hong Kong Convention, and evidence-based policymaking. Environmental and labor NGOs benefit from greater transparency in e-waste handling, access to safety documentation, and verified records for fair labor advocacy. Auction houses and secondary markets gain buyer trust through verified product histories, material grading, and streamlined resale. Shipowners and brokers benefit from enhanced ESG reporting, investor confidence, and integration with shipyard ERP systems, supporting a shift from tonnage-based to material-based valuation and enabling full lifecycle traceability.

Figure 3: Blue Vigil benefits for Regulatory Bodies (IMO, HKC, UN)
Enhanced traceability supports improved IHM monitoring, data-driven enforcement, and future policy refinements.

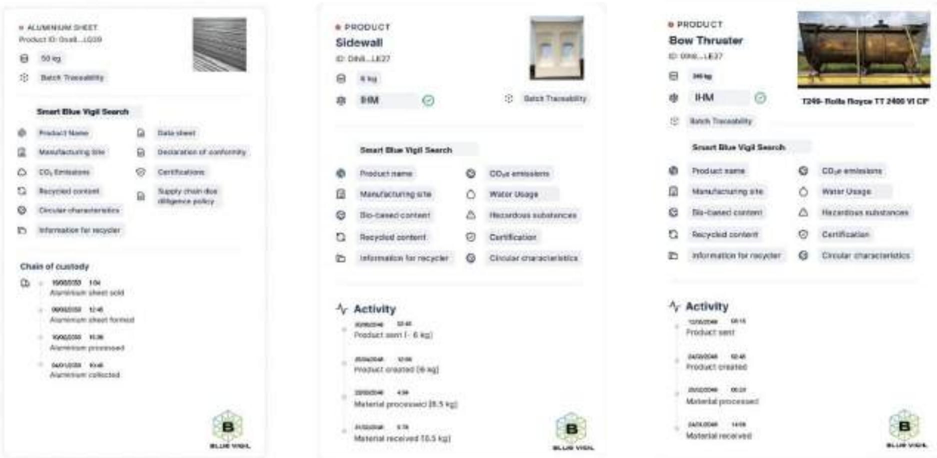

Figure 4: Blue Vigil benefits for Auction Houses and Secondary MarketsDigital listings and transparent bidding facilitate reuse and resale of dismantled parts, supporting circularity.

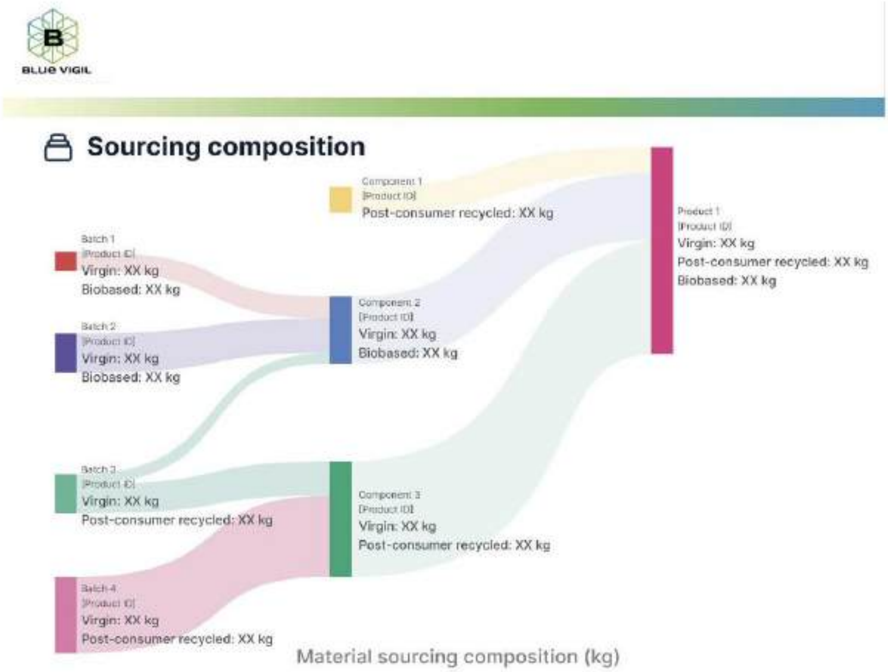

Figure 5: Blue Vigil benefits for IHM Compliance Brokers Streamlined IHM verification through centralised data integration improves hazardous material identification

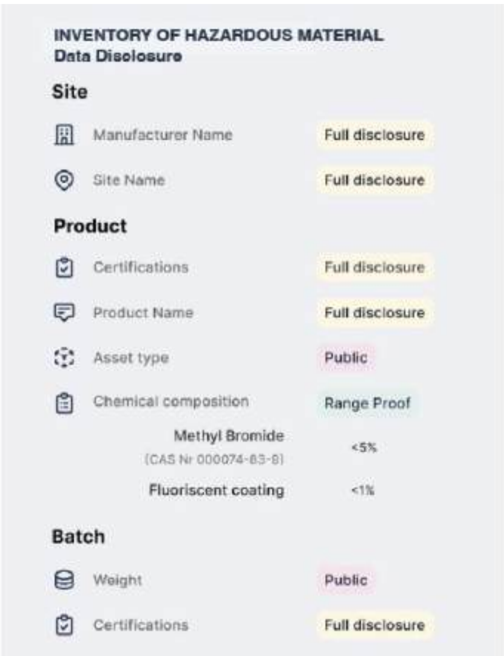

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Figure 6: Blue Vigil benefits for IHM Compliance Brokers Selective data disclosure

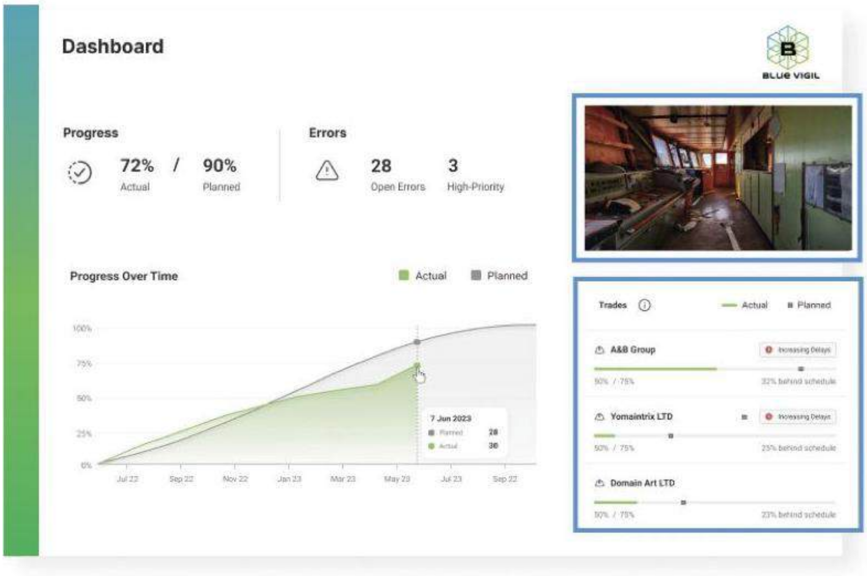
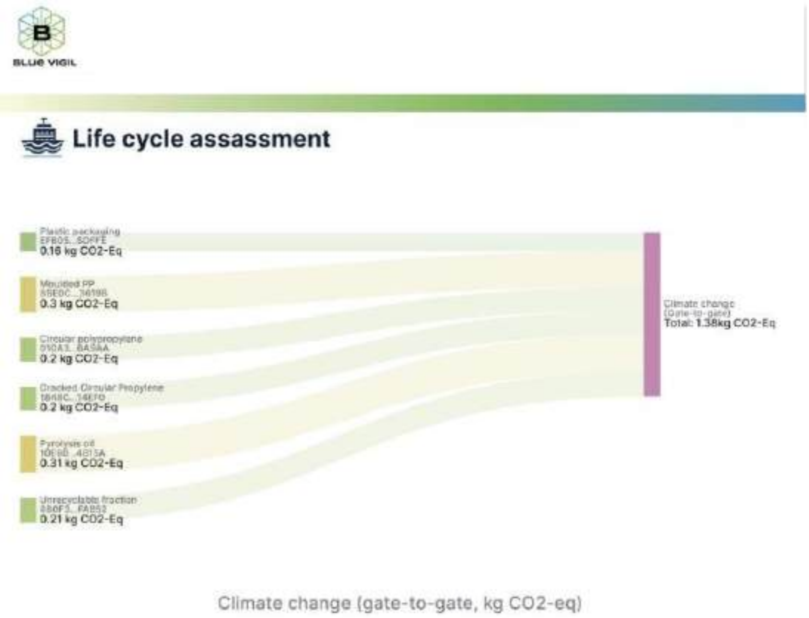


Figure 7: Blue Vigil benefits for Shipbreaking Yards Blue Vigil improves safety, efficiency, and transparency in shipbreaking yards countering negative perceptions of unsafe, low-compliance operations like those in Alang.



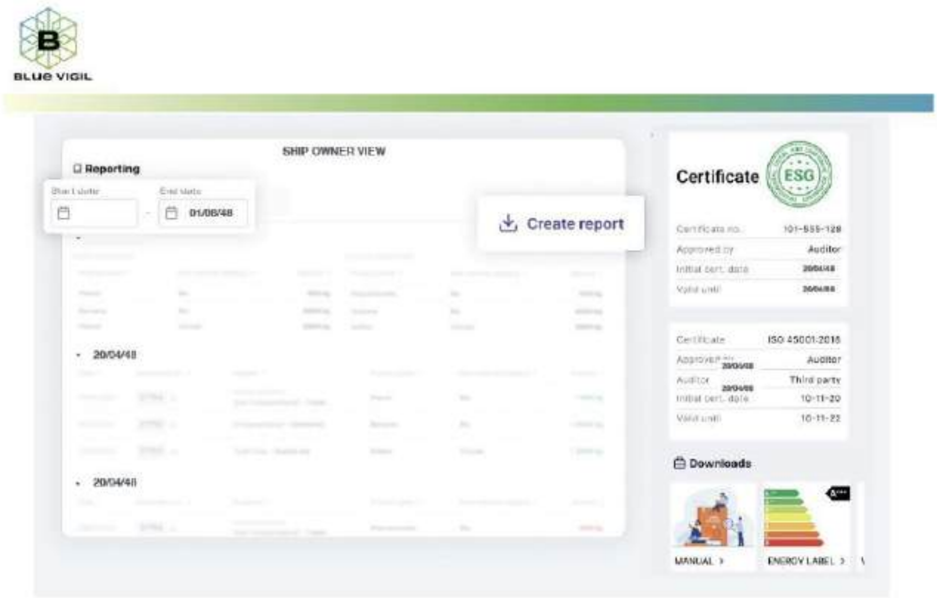


Figure 8: Blue Vigil benefits for Ship Owners ‘Ship as a product’ Blue Vigil enables lifecycle-based ship valuation through Digital Product Passports, enhancing ESG compliance and moving beyond tonnage-based dismantling metrics.

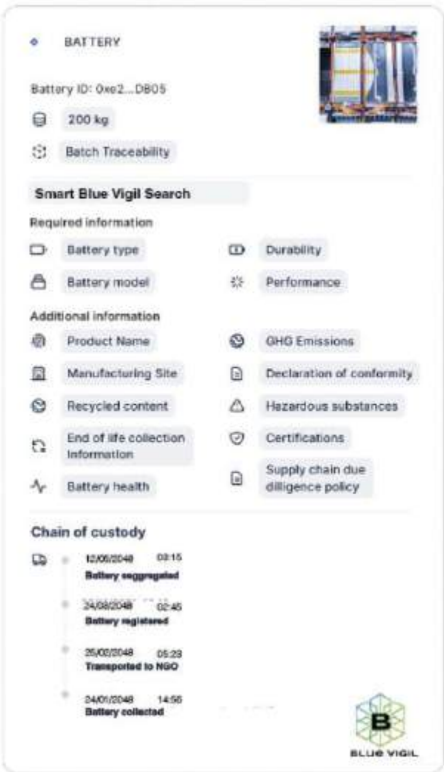


Figure 9: Blue Vigil benefits for NGOs Blue Vigil helps NGOs advocate for fair labour by maintaining verifiable records of materials processed through informal markets.

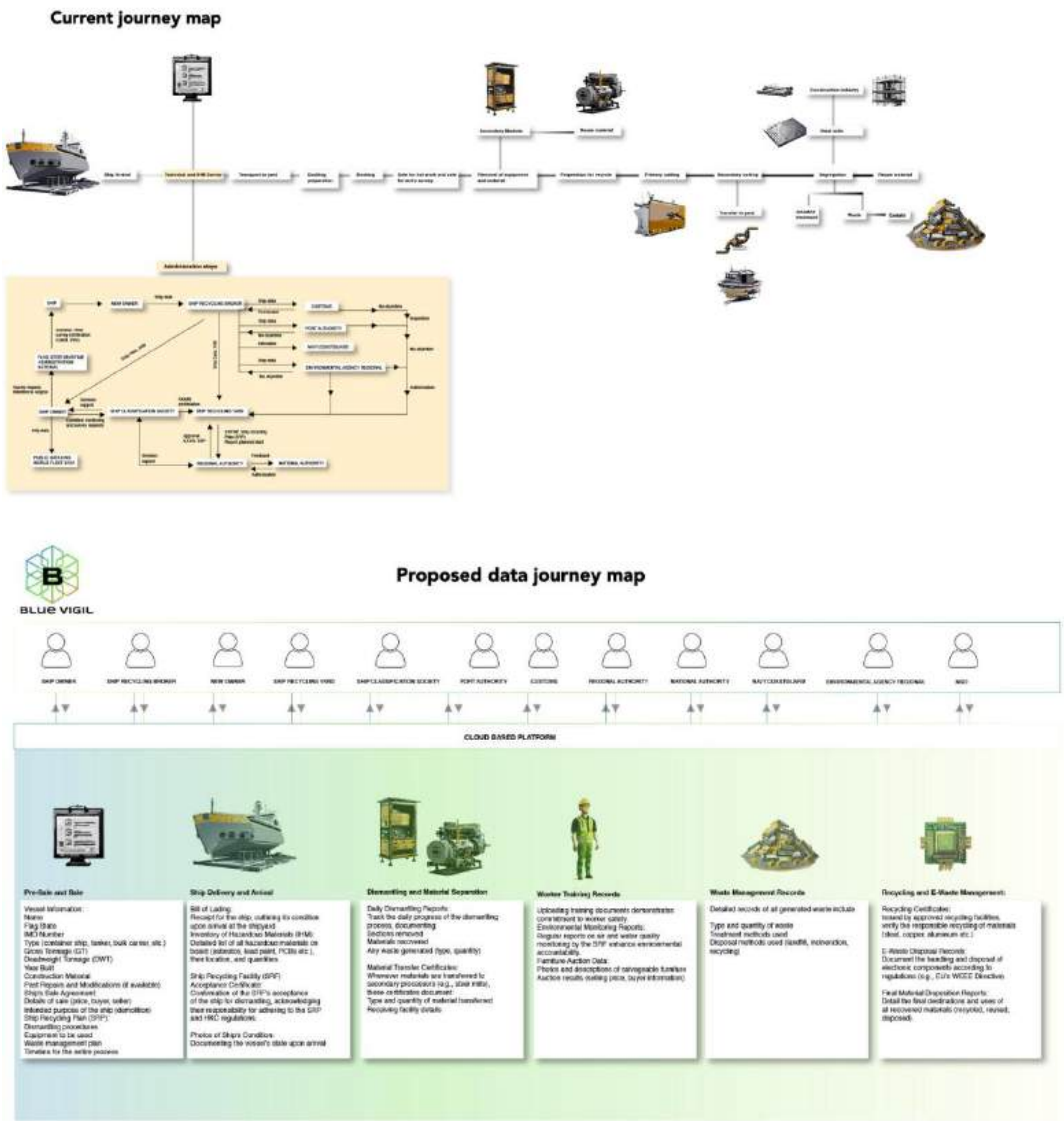


Figure 10: Comparative data journey maps of the current system vs after Blue Vigil

Transition Roadmap

Futures design methodologies offer an opportunity for envisioning, exploring, and co-creating a shared vision toward sustainable transitions in complex, multi-stakeholder industries such as ship recycling. The roadmap integrates technological, policy, and socio-cultural advancements. A long-term roadmap envisions Alang transitioning into a model circular ship recycling hub by 2050.

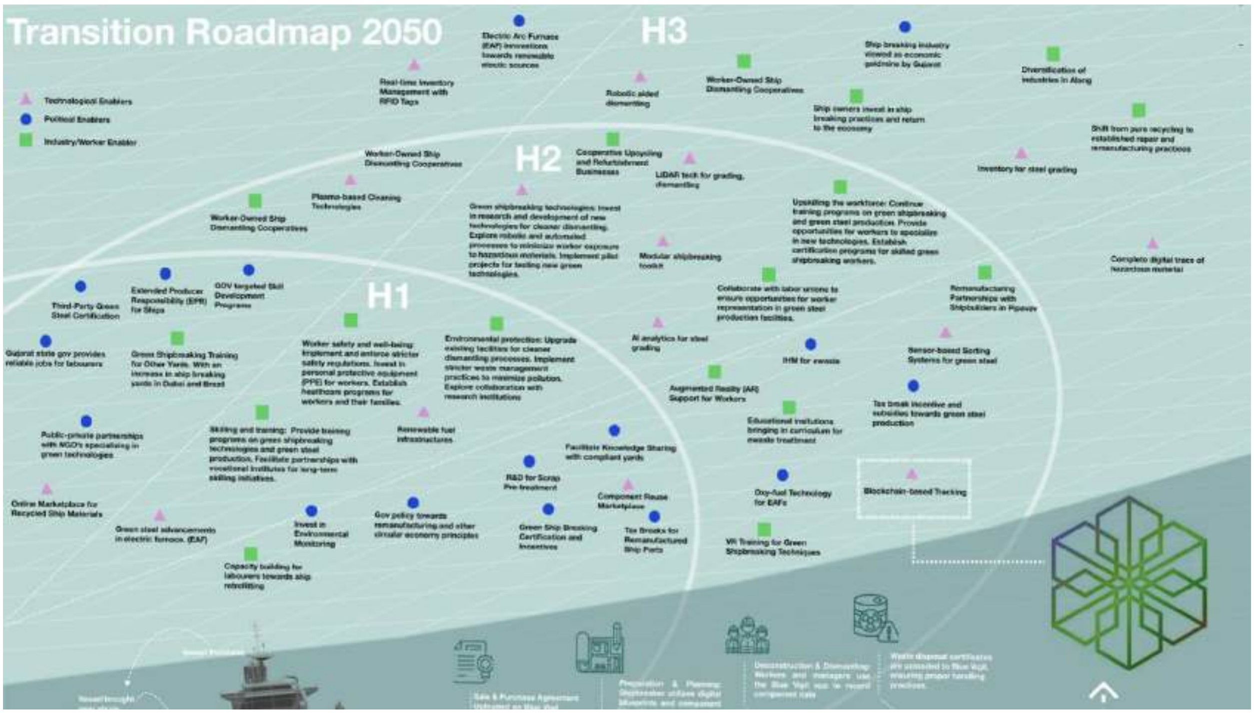


Figure 11: Transition Roadmap for a Transparent and Sustainable Shipbreaking Industry

Key milestones along this trajectory include:

- **Infrastructure Upgrades:** Development of advanced dry docks and sealed yards to mitigate environmental contamination and enhance operational efficiency.
- **Workforce Retraining:** Comprehensive reskilling programs focused on hazardous waste management and the integration of AI-assisted dismantling technologies, ensuring safer and more efficient labor practices.
- **Scaling the Adoption of Blue Vigil:** Implementing the blockchain-based platform to enable transparent tracking accountability, and traceability across the shipbreaking value chain.
- **Formation of Public-Private Partnerships:** Collaborative frameworks between government agencies, industry players, and civil society to foster a transparent, circular steel and ship recycling economy grounded in shared responsibility and trust.

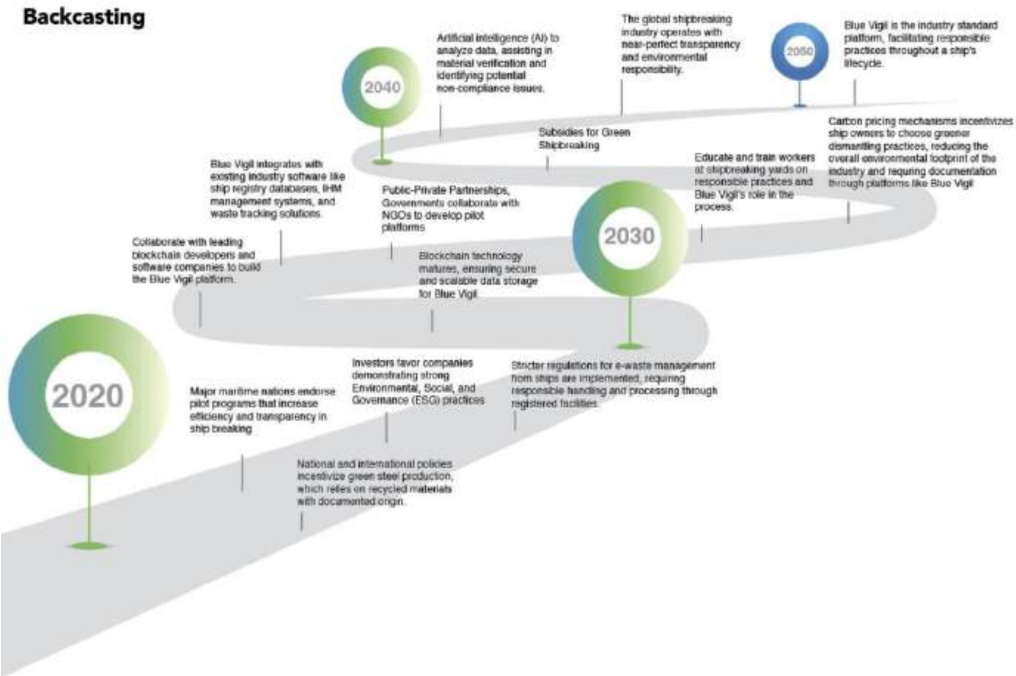


Figure 12: Backcasting exercise towards the development of Blue Vigil.

Discussion

Efforts to embed transparency and accountability within the global shipbreaking industry must contend with deeply entrenched socio-technical complexities. As highlighted by the IndustriALL Global Union and the International Maritime Organization (IMO, 2023), the ship recycling sector is shaped by informal labour economies, limited regulatory oversight, and asymmetrical power structures between global shipping companies and local dismantling communities. These dynamics create friction for the implementation of traceability interventions, which often emerge from formal, technocratic systems.

Blue Vigil, as a speculative design intervention, serves as a prototype that stimulates critical discourse around how traceability systems might evolve, who gets included or excluded, and what cultural frictions they introduce, examining who benefits and who may be excluded.

While digital platforms promise improved transparency and compliance, they tend to privilege actors with institutional capacity such as shipowners, brokers, and certified yards while marginalising informal stakeholders like component resellers or unregistered workers who often lack digital access, infrastructure, or literacy. Without inclusive design and stakeholder buy-in, these actors risk exclusion from emerging value chains, potentially losing income or facing penalties for non-compliance (Hielscher et al., 2021). Importantly, the findings reaffirm that unintended consequences such as digital exclusion, mistrust, or the reinforcement of existing hierarchies, must be considered in the design of traceability systems like Digital Product Passports. (Ducuing & Reich, 2023; Matters Journal, 2024). The success of such technologies hinges not only on technical infrastructure but on trust, accessibility, and governance. Futures design methodologies provide the opportunity to explore these tensions in advance, enabling iterative development that is both inclusive and context-responsive.

Conclusion

This research identifies key barriers and opportunities and demonstrates traceability, accountability, and operational visibility as pivotal tools for transitioning toward a fully circular economy. Interventions such as blockchain-enabled Digital Product Passports (DPPs) offer scalable approaches to material traceability and regulatory compliance that can be adapted to other regions and industries facing similar complexities. The shipbreaking industry has the potential to become a global model for circular economy practices, influencing not only its immediate stakeholders but also inspiring systemic change in other resource-intensive sectors. In doing so, this research highlights the broader potential of design-led methodologies to co-create actionable and preferable business futures.

Future Work

This research lays the groundwork for a doctoral study commencing in 2025, in partnership with the Sustainable Shipping Initiative (SSI), which will investigate the unintended consequences of transitioning to a circular economy within the global shipping industry. Central to this study will be the development of a Circular Maritime Futures Framework (CMFF). Field visits to Alang and London will provide critical, on-the-ground insights into both operational realities and international regulatory contexts. Through co-design workshops, diverse stakeholders will collaboratively envision alternative futures and develop interventions aligned with circular economy principles. participatory engagements will guide the creation of roadmap tools, speculative narratives, and future scenarios framed by varying levels of regulatory enforcement and technological adoption, including Digital Product Passports (DPPs). The research outcomes will be widely disseminated via visual storytelling, policy briefs, academic publications, and collaborative design artifacts.

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One for One: Vodafone Germany & Closing the Loop's Customer-Centric and Pragmatic Circularity Leads to the Recovery of over 2.7 Million Scrap Phones

Joost de Kluijver

Co-Founder & CEO

Closing the Loop

The Netherlands

Abstract

The telecom industry has driven global connectivity and economic growth for decades. However, it has struggled to address one of its biggest environmental challenges: electronic waste. Global e-waste is projected to reach 82 million tonnes by 2030 yet most phones evade formal recycling. Despite growth of compliance-driven initiatives, the industry has lacked a scalable and commercially viable business model. In 2022 Vodafone Germany and Closing the Loop launched One for One, embedding sustainability into the customer journey: for every new phone sold, one end-of-life device is collected and recycled in regions like Ghana and Nigeria. This initiative bridges the gap between high-tech consumption in Europe and e-waste challenges in Africa, proving that circularity can be scalable, inclusive and consumer friendly. Since its launch, One for One has resulted in important social, environmental, and business benefits. This pragmatic circular model turns sustainability into a strategic growth driver and provides a scalable blueprint for other companies.

1. The Challenge: E-Waste in a Connected World

1.1 Global Telecom Consumption: Short Lifespans, Long-Lasting Waste

Telecommunications have revolutionized the modern world by transcending geographical barriers and enabling instant global connectivity. As one of the most transformative inventions of the late 20th century, the mobile phone has enabled people around the world to connect, work, bank, and learn in ways previously unimaginable but this global rise in connectivity comes with an environmental cost.

According to the International Telecommunication Union (ITU), in 2023, there were more than 8.9 billion mobile cellular subscriptions in use globally, surpassing the world's population of 7.95 billion (ITU 2023). This reflects not only near-universal access but also a growing trend of individuals owning multiple devices. Yet, the rapid pace of technological innovation and consumer upgrade cycles means most phones become obsolete within just a few years: the in-use lifespan[1] of smartphones is approximately 1.98 years, while that of feature phones[2] is around 2.46 years (Abbondanza & Souza 2019). As the number of active subscriptions continues to rise and device lifespans shrink, the volume of discarded phones is increasing sharply, contributing significantly to the global e-waste crisis.

Worldwide, the annual generation of e-waste is rising by 2.6 million tonnes annually, on track to reach 82 million tonnes by 2030 (United Nations Institute for Training and Research 2024). Small electronic equipment[3] items are the single largest stream of global e-waste, generating 17.4 Mt in 2021. This was over 4 Mt more than any other category and accounting for almost one-third (32.5 %) of the world's total. Although phones are only part of that stream, they are uniquely problematic. Each year, millions of quickly obsolete devices flood the waste stream seldom collected or recycled and often hoarded at home or improperly disposed of in bins destined for landfills or incinerators.

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[1]The in-use lifespan refers to the average time a device remains in use before it is replaced, not its technical life expectancy.
[2]Feature phones are basic mobile phones with limited functionality compared to smartphones (e.g., calls and texts, no apps).
[3] "Small electronic equipment" refers to electrical and electronic devices whose external dimensions do not exceed 50 cm. This category encompasses a wide range of consumer and IT products, including mobile phones, tablets, digital cameras, printers, and other similarly sized gadgets.

Meanwhile, it is estimated that, every year, 3.3 billion kg of e-waste are moved through uncontrolled transboundary shipments, much of it ending up in Africa where the demand for used devices has historically been significant. These flows contribute to the unsafe accumulation of toxic waste in regions least equipped to manage it (Baldé et al. 2024). Ironically, these discarded phones still harbour valuable raw materials gold, silver, and palladium (Maragkos, Hahladakis & Gidarakos 2013) but rather than entering formal recovery streams, they're too often subjected to open burning or acid leaching. Such informal processes not only destroy recoverable resources but also liberate hazardous substances into soil, air, and water, imperilling environmental and human health.

1.2 The Ineffectiveness of Current Market Approaches

Although the challenge of e-waste is continuously gaining in awareness, many of the telecom industry's existing solutions remain limited in scope, scale, and effectiveness, often targeting only the most valuable or easily reusable and recoverable devices. Trade-in schemes, for example, are typically designed for newer models in good condition. These programs cater to developed markets and rarely operate in countries where the problem of uncollected e-waste is most severe.

Repair initiatives, on the other hand, face a different set of barriers, including the high cost of replacement parts and the limited availability of tools and specialty knowledge. These challenges are compounded by the perception that repairing a phone is more expensive and less reliable than buying a new one. Similarly, refurbished smartphones, though fully functional, often suffer from low consumer trust and status-related stigma. The preference for new devices is reinforced by marketing strategies and perverse commercial thinking that link the latest model with social belonging and personal identity. As Oraee et al. (2024) note, this leads to the premature discarding of devices that are still usable, driven by both planned and perceived obsolescence[4], especially among younger users.

1.3 The Ineffectiveness of Current Legal Approaches

As of mid-2023, only 81 out of 193 countries (42 percent) have any national e-waste policy, legislation, or regulation in place and of those, just 67 apply Extended Producer Responsibility (EPR) schemes, 46 set formal collection targets, and only 36 mandate recycling-rate targets (ITU 2024). Enforcement remains a genuine global challenge, hampered further by the Basel Conventions[5] "Conventions broad definitions and inconsistent oversight, which exporters routinely circumvent by labelling waste as reusable equipment.

Because so few nations maintain robust e-waste laws, most compliance-driven programs centre on minimal compliance rather than true circularity, focusing narrowly on meeting legal obligations or reducing reputational risk. These compliance-driven initiatives fit within a linear production consumption model that deals primarily with back-end waste management[6], largely ignoring the vast number of phones that flow through informal markets, where limited infrastructure and weak enforcement make formal recycling unlikely.

Furthermore, most compliance initiatives are shaped by local conditions such as available infrastructure, national regulations, and economic incentives and operate in isolation. Wealthier nations may enforce strict recycling and EPR requirements, while lower-income regions that import second-hand electronics lack both resources and incentives for safe disposal. As mobile phones circulate through a global supply chain, the systems responsible for managing their end-of-life impact often fail to match that global scope and to link regions of high consumption with those bearing the brunt of disposal burdens.

[4]Planned obsolescence refers to designing products with a deliberately limited useful life; perceived obsolescence occurs when consumers believe a product is outdated due to design or branding, even if it still functions.

[5]Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal; an international treaty designed to reduce the movement of hazardous waste between nations, especially from developed to developing countries.

[6]In this context, "back-end waste management" refers specifically to the formalized processes that occur after an electronic device has been collected through regulated, officially recognized systems.

1.4 The Case for Innovation Beyond Compliance

The limitations of current government led e-waste initiatives point to a broader opportunity: to reimagine circularity not as a regulatory burden, but as a business-enabling strategy. As consumption accelerates and global supply chains become more complex, the most impactful and truly sustainable solutions will be those that align environmental value with commercial logic. This means moving beyond compliance and toward models that are business-friendly, scalable, and integrated into the everyday processes of how electronics are bought, sold, and used.

It is important to note that commercial logic alone is not enough consumer participation must also be part of the equation. Scholars argue that voluntary, incentive-aligned systems often achieve greater scalability and adoption than regulation alone. Bocken et al. (2016) outline strategies that support circular business models through product longevity, disassembly, and material recovery, making sustainability more achievable within current commercial systems. Similarly, Kirchherr et al. (2018) emphasize that consumer participation is vital to circular success, yet behaviour change remains a significant barrier. They suggest that practical, business-integrated solutions offer the best chance of meaningful progress.

This builds the case for a concept known as ‘pragmatic circularity’. Here, it is acknowledged that most consumers especially in high-income countries are unlikely to change their current behaviour unless sustainability is integrated into everyday routines, such as product purchases or upgrades. By integrating simple, ‘painless’ circular services into existing commercial flows, business-led initiatives can significantly lower the barrier to participation and establish scalable systems for resource recovery. These solutions do not require radical lifestyle shifts; they work because they meet consumers where they already are.

Forward-thinking models that embed sustainability into real-world touchpoints show that a first step toward circularity must be simple, effective, and commercially viable. In practice, Closing the Loop’s One-for-One model shows that when recycling is as easy as buying a new device, circularity shifts from a regulatory checkbox to a genuine business opportunity.

2. One for One: A Pragmatic Circular Business Model

2.1 What It Is: A Simple Proposition with Global Impact & Reach

One for One is a circular service model developed by Closing the Loop and offered by companies such as Vodafone Germany. With One for One, Closing the Loop helps turn circular thinking into a service that is appealing to customers and supportive of business goals, within the tech industry. Launched in 2022, the model introduced a scalable yet straightforward concept: for one new phone sold by Vodafone Germany to their direct customers, one scrap phone is collected and responsibly recycled by Closing the Loop.

Unlike traditional offsetting models that rely on abstract and complex (if not dubious) calculations, this one-to-one mechanism transforms device consumption into a simple, closed-loop exchange. It reframes sustainability from something optional, or even bothersome, into something automatic, seamlessly and positively embedded in the customer journey. Vodafone links this environmental action to a high-engagement moment: the purchase of a new phone, turning waste reduction into a natural part of the product experience.

One for One labels circularity as a ‘service’ a solution that requires no opt-in, no extra cost, and no behavioural change. Being fully financed by Vodafone, the service is both inclusive and frictionless for the customer. Crucially, the model fits within the existing device-sales ecosystem. When customers receive a new device, the One for One program is applied automatically. Behind the scenes, Closing the Loop ensures ethical, traceable collection and recycling. The combined effort results in a model that delivers measurable commercial, environmental, and social impact, without disrupting commercial flows.

2.2 How It Works: Supply Chain, Logistics, and African Collection Networks

Under the One for One model, each new device delivered triggers the collection of an end-of-life one. Since 2012, Closing the Loop has managed waste collection through its partner network in African markets such as Ghana and Nigeria. Local agents, trained and supported by Closing the Loop, source irreparable phones from repair shops, schools, churches, and community members. These scrap devices are purchased at a fair price, creating financial incentive that fosters inclusion and dignity in the informal sector. The reverse supply chain operates in two key phases: upstream collection and downstream recycling[7].

Upstream collection is organized across multiple tiers:

Tier 3+: Grassroots-level collectors, including local repair shops, waste associations, and community centres. These collectors operate informally and are not known to Closing the Loop.

Tier 2: Aggregators who gather devices and transport them to local hubs; most of these partners are known by Closing the Loop.

Tier 1: Local Service Providers (LSPs), who manage warehousing, inspections; all operate under direct contracts with Closing the Loop.

LSPs are responsible for sealing, labelling, and storing each batch of collected waste, as well as removing batteries to reduce fire risk. All collected phones are correctly registered and tracked in an online tool before being packed for shipment, making the process traceable and transparent. This tool also provides proof of the One-for-One claim: batches of devices are earmarked for specific customers (for example, 1,000 new phones delivered by Vodafone correspond to 1,000 end-of-life devices collected in Ghana). Closing the Loop performs regular audits and stock checks to ensure full traceability and compliance. Once thresholds are met, devices are exported to proper recyclers under the Basel Convention.

Downstream, certified recycling partners recover valuable metals such as copper, gold, and silver using environmentally sound methods. These recyclers are vetted against Closing the Loop's Supplier Code and strict European regulatory standards. The recovered metals are then offered as sustainable raw materials, completing the loop and reducing the demand for virgin mining.

By combining traceable collection with responsible recycling, Closing the Loop delivers a full chain of custody and a closed-loop system that removes e-waste from vulnerable ecosystems, generates verified environmental impact, and creates economic opportunity for local communities.

2.3 Making It Viable: Integrating Sustainability into Mobile Sales

The viability of One for One stems from its seamless integration into existing commercial systems. Rather than immediately mandating new behaviours, channels, or workflows (requirements that often explain the slow adoption of more intrusive approaches), the model fits naturally into Vodafone's established customer journey, turning a standard phone purchase into a positive action by default.

From a business perspective, this seamless integration elevates circularity from a niche initiative to a core brand feature. It provides Vodafone with a credible, consistent narrative that reinforces both its marketing strategy and long-term innovation goals. Instead of framing One for One as a compliance obligation, the brand positions it as a customer-centric, value-added service that differentiates Vodafone in a competitive market.

Internally, the program is a cornerstone of Vodafone’s 2025 circular-economy target to reuse, resell, or recycle 100 percent of its network waste (Vodafone Group, 2021) and advances its net-zero ambitions across Scopes 1, 2, and 3. Crucially, One for One complements rather than replaces trade-in or resale schemes and is designed for the majority of customers who otherwise wouldn’t engage in any circular offering.

3. Results That Matter: Environmental, Social, and Commercial

3.1 Key Environmental Metrics of One for One (2022–2025)

Since the launch of Vodafone's One for One program, over 2.7 million devices have been covered by the service, preventing more than 154 tonnes of electronic waste from ending up in landfills and

[7]In this context, "upstream" refers to local collection in African countries; "downstream" refers to recycling processes in Europe.

instead redirecting valuable materials back into the circular economy[8]. Thanks to the responsible recycling of these devices, an estimated 10,600 kg of copper (537 km of copper cable), 57 kg of silver (760 silver spoons), and 8 kg of gold (two World Cup trophies) have been recovered and reintegrated into supply chains, reducing the need for virgin mining and supporting material circularity (Vodafone Germany, 2024). The program has also prevented hazardous substances from leaking into the environment.

These results have made One for One one of the world's most extensive mobile phone waste recycling programs in the telecommunications industry. Vodafone is among the first major telecom operators in Europe to implement a large-scale circular business model that compensates for electronic waste associated with consumer sales. With over 1 million new phones made waste-neutral annually, Vodafone Germany and Closing the Loop have demonstrated that responsible electronics consumption can scale when paired with simple, service-based models embedded in consumer journeys.

3.2 Social Outcomes: Safe Income Opportunities for African Partners

A significant proportion of e-waste management in Africa is handled by the informal sector[9], which often lacks equipment, safety standards, or regulatory oversight. The Global E-waste Monitor (2024) highlights the need to integrate informal workers into formal systems aligning with CTL’s model which provides registration, training, and safety equipment to grassroots collectors. Approximately 70% of Closing the Loop’s investment goes directly to individuals in the informal sector, offering stable income while professionalizing e-waste handling.

Informal collectors often earn higher returns per device by skipping formal protocols, so adding safeguards such as registration, training, and safety equipment can slow productivity and raise costs. To bring these workers into a professional, safe system, Closing the Loop provides extra income that fully offsets any productivity loss and ensures industry-standard wages and environmental compliance. In countries like Ghana and Nigeria, Closing the Loop's standard operations support 152 full-time jobs and 320 part-time jobs, with most of these positions paying significantly above the minimum wage. Since its launch, One for One has helped generate an overall of 6,000 living wages[10] or community members involved in safe collection. The service not only replaces harmful practices like open burning but also empowers local actors with tools, training, and a cleaner, more sustainable income stream (Vodafone Germany 2024).

Central to One for One’s success are the people who make it possible. Collectors, consumers, and corporate partners are all part of the same story. Closing the Loop captures and shares real testimonials from its local network, bringing visibility to the people who make the system work. By connecting lived experiences in the Global South with the act of phone consumption in Europe, One for One creates both emotional and material value. It bridges two ends of the global electronics chain, revealing that behind every device is a person, and behind every scrap phone, a second chance.

3.3 Business Outcomes: Differentiation, Reputation, Customer Engagement

From a corporate perspective, One for One bolsters both Vodafone Germany’s environmental and brand strategy by fulfilling a unique customer promise providing “waste-neutral” phones with no extra cost or effort to the consumer. According to Vodafone, this makes sustainability a "trust-building element,” demonstrating circularity’s marketing power. One for One was not positioned as an obligation but as a brand differentiator a clear, compelling service that builds trust and adds value.

At the 1.5 million milestone, Vodafone decided to launch a major PR campaign that was integrated into customer communications both via social media and internal communication tools. The campaign

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[8]A circular economy is a system that keeps materials in use for as long as possible, recovering and regenerating products at the end of their service life.

[9]The informal sector includes workers and businesses not regulated by the state, often lacking legal protection or access to social benefits

which also carries a 7-minute documentary of the work done in Accra[11] has resonated widely, reaching over 30 million people and receiving five sustainability and communication awards, including the German Sustainability Award and the 2025 SABRE Award[12] for Best DACH[13] Campaign. Vodafone's customer-centric communication strategy proved instrumental in engaging new audiences and driving industry-wide recognition.

In an industry where sustainability claims often suffer from a "say-do gap"[14], One for One stood out by delivering real, understandable, and measurable impact, bridging the gap between brand promise and consumer experience. Rather than relying on long term, abstract pledges, Vodafone offered a tangible, easy-to-understand service that made environmental impact part of the everyday purchase journey, complementing their green portfolio which includes other offerings such as reuse, repair and the direct buying of used devices.

4. Collaboration as the Platform for Innovation and Growth

4.1 Vodafone's Scale Meets Closing the Loop's Circular Expertise

Vodafone Germany's partnership with Closing the Loop illustrates what happens when commercial scale is combined with operational circularity. Together, they integrated a simple but powerful service waste compensation into a major consumer offer, demonstrating that circularity can be understood and embedded, not bolted on. Vodafone brought reach, visibility, and a large customer base ready to engage. Closing the Loop contributed a credible, proven operational model and the expertise to deliver it. The result is one of the world's most significant mobile phone recycling initiatives: a national-scale circular solution that turns every phone sale into a closed-loop transaction.

The success of One for One lies in mutual value creation and shared ambition. Vodafone was not a passive client but an active co-creator. While the service can be seen as an off-the-shelf product, it was jointly tailored to Vodafone's brand, business goals, and customer experience. From program design to campaign roll-out, Vodafone and Closing the Loop worked hand in hand to build something that was both commercially relevant and operationally sound.

This co-creation extended to joint storytelling, milestone campaigns, and customer-facing materials that reinforced Vodafone's credibility and impact. At the same time, the partnership enabled Closing the Loop to scale its model, strengthen its supply chain, and expand its footprint across Africa and Europe. Ultimately, the partnership marked a turning point: proof that commercial collaboration can unlock circular innovation at scale and lay the groundwork for systemic change.

4.2. Looking Ahead: Replication and Expansion

With over 2.7 million phones already collected, Vodafone Germany and Closing the Loop aim to recover at least 1 million more devices within the next year, demonstrating that circularity at scale is not only possible but also commercially viable. The model offers a replicable blueprint for how tech companies can start operationalizing SDG 12[15] without any immediate infrastructure investments or significant shifts in consumer behaviour. By positioning sustainability as a business opportunity rather than a compliance requirement, the model sets a new benchmark for circular partnerships, proving that they can be inclusive, scalable, and profitable.

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[10]A living wage refers to an income that covers basic needs such as food, housing, healthcare, and education — generally higher than the legal minimum wage.
[11]Accra, the capital of Ghana, is one of Closing the Loop's key collection hubs where informal e-waste work is being formalized through traceable systems.
[12]The SABRE Awards (Superior Achievement in Branding, Reputation, and Engagement) are international PR awards.
[13]The German-speaking region of Germany (D), Austria (A), and Switzerland (CH).
[14]The "say-do gap" refers to the disconnect between what organizations publicly promise and what they deliver in terms of sustainability or CSR impact Accra, the capital of Ghana, is one of Closing the Loop's key collection hubs where informal e-waste work is being formalized through traceable systems.
[15]Sustainable Development Goal 12 focuses on responsible consumption and production, including waste reduction and resource efficiency.

For Vodafone Germany, One for One is just the beginning. By embedding sustainability into a familiar customer interaction, the program establishes the foundation for deeper engagement and future innovation. It helps educate consumers, build trust, and create the conditions for more ambitious circular initiatives across the company's product lifecycle from take-back and repair to modular design and service-based models. As a result, One for One offers the perfect starting point on the long journey towards circular tech, both for the industry and its customers.

In parallel, thanks to the partnership, Closing the Loop is expanding its proven waste-compensation model to include other electronic categories such as tablets, laptops, monitors, and batteries. Its modular structure makes it adaptable across a wide range of IT assets wherever electronics are sold, used, or discarded. The company's next milestone, however, reaches even further: establishing Africa's first compliant[16] e-waste smelter[17]. Today, no viable business model exists for legal smelting on the continent. Weak regulatory enforcement and the prevalence of harmful, informal operations have long hindered the development of formal infrastructure.

Through its partnership with Vodafone Germany, Closing the Loop has demonstrated the ability to consistently collect and export scrap phones via traceable, ethical channels evidence of a stable, scalable supply chain. This success lays the groundwork for localized processing. If supported by stronger legislation and enforcement mechanisms, the new facility expected to enter development within the next two years could eliminate the need for export and retain both material and economic value within the region. Such a facility would "close the loop" in a far more literal and locally empowering way.

5. Conclusion: Redefining What is Possible Today in Circular Business

With over 2.7 million phones collected and thousands of living-wage opportunities generated, One for One proves that sustainability can be both frictionless and commercially powerful. By embedding a simple take-back service directly into the purchase process, Vodafone Germany turned waste compensation from an afterthought into an automatic, value-added feature demonstrating that real impact and business growth can reinforce each other at scale.

At its core, One for One relies on a human-centred design that makes participation effortless: when a customer buys a new device, Closing the Loop handles the responsible recycling of an end-of-life one. This shared-responsibility approach lowers barriers, builds trust, and drives repeat engagement without demanding consumer behaviour change.

Other industries can draw important lessons from this initiative. Being modular, transparent, and built on real incentives, the One for One model is applicable far beyond telecom, offering a scalable blueprint for any sector ready to move from intention to impact in a business-friendly and customer-centric way. Any company can adopt the blueprint by selecting a product category and defining a clear one-for-one collection-for-purchase ratio.

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[16]Compliant means the facility would meet international environmental and labour standards for processing electronic waste.
[17]E-waste smelters are specialized pyrometallurgical facilities that melt shredded electronic scrap to separate and recover base and precious metalsSustainable Development Goal 12 focuses on responsible consumption and production, including waste reduction and resource efficiency.

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Antecedents, Moderators, Mediators, and Outcomes of Circular Business Models: A Systematic Literature Review

V.Litaudon
Senior Project Coordinator
University for the Creative Arts
United Kingdom

Meryem Altaf
Lecturer in Business & Management
De Montfort University
United Kingdom

Meera Borsara
Senior Lecturer in Business & Management
De Montfort University
United Kingdom

The path from a linear to a Circular Economy (CE) is critically dependent on the adoption of Circular Business Models (CBMs), yet research on their underlying mechanisms remains fragmented and descriptive. This research bridges the gap by using a Systematic Literature Review (SLR) to establish the Antecedents-Mediators-Moderators-Outcomes (AMMO) framework. The proposed framework uniquely advances the field by offering a structured, causal model that specifies not only the drivers of CBMs but also the enabling mechanisms and contextual factors that shape their implementation and outcomes. Our findings reveal a diverse set of antecedents and outcomes, while highlighting key mediators such as organisational collaboration and critical moderators like technology and policy. Crucially, we demonstrate how this framework facilitates the development of empirically testable propositions, thereby integrating a fragmented literature into a structured, predictive theoretical framework. This study provides a vital tool for both researchers seeking to build upon existing theory and practitioners aiming to drive effective circular transitions.

The Just Fashion Project: EU Policies Transforming the Fashion and Textile Sector .

V Litaudon

Senior Project Coordinator

University for the Creative Arts

United Kingdom

The Just Fashion project is a collaborative initiative aimed at accelerating the climate transition in the fashion and textile industry by providing businesses, particularly SMEs in partner countries, with a reference framework and practical tools to shift towards low-carbon, circular, and socially inclusive models. A key component of the project is the analysis of the evolving EU policy landscape that is reshaping the sector. The European fashion and textile sector is entering a decisive transition as new EU policies are redefining how products are designed, produced, managed, and communicated across their entire lifecycle. This session will provide an overview of the evolving regulatory landscape, with a focus on the Ecodesign for Sustainable Products Regulation (ESPR) and its key features, including the Digital Product Passport (DPP), ecodesign requirements, restrictions on unsold goods, and timelines for implementation. Complementary legislation, ranging from the Waste Framework Directive and Extended Producer Responsibility schemes to the Corporate Sustainability Reporting Directive (CSRD), Corporate Sustainability Due Diligence Directive (CSDDD), and the Green Claims Directive will be explored in relation to their combined impact on the industry. Building on insights from the Just Fashion project, the presentation will put forward recommendations and a practical checklist to support SMEs in anticipating regulatory compliance, enabling them to navigate the rapidly evolving policy landscape.

The Maze of Circularity Standards Landscape

Pradeep Mahat

Circular Economy Standardization Lead

Nokia Oyj

Finland

Susanna Kallio

Head of Sustainability Standardization

Nokia Oyj

Finland

Abstract

The transition to a circular economy, by decoupling economic activities from resource consumption and environmental impact, is crucial in addressing global challenges like climate change, biodiversity loss, resource depletion, waste and pollution. To support the circular transition, a unified, robust and consistent framework for assessing and enhancing circularity is needed.

Standards play a crucial role in unifying understandings and assessment approaches. However, the complex and multifaceted nature of the circularity concept has led to the development of diverse standards and guidance. This has resulted in different approaches and terminologies. These approaches range from design and concept level assessment to circularity score and indicators and standards assessing the secondary effect of circularity.

This paper analyzes the current circularity standardization landscape focusing on key circularity standards relevant to the Information and Communication Technology (ICT) sector and identifies the gaps, similarities and differences in the approaches.

1 Introduction

The urgent need for a circular economy (CE) stems from the escalating pressure on our planet, particularly the depletion of natural resources and the environmental consequences of linear "take, make, and dispose" practices. To date, six out of the nine planetary boundaries that define the safe operating limits for the Earth's systems, have already been breached (Richardson, et al., 2023) and global extraction of natural resources has tripled since 1970, reaching a staggering 100 billion tons annually but only 7.2% of the materials are fed back to the economy. These numbers are getting worse every year due to increasing extraction. (CGR, 2024) The extraction and processing of resources for hardware manufacturing, energy used, and disposal of products has a negative impact on the ecosystem contributing to climate change, biodiversity loss, pollution, and water stress. A holistic approach, addressing air (climate), biodiversity and geodiversity, is needed to mitigate these environmental impacts. (Tanskanen, et al., 2023) CE has intersections in all three aspects.

At its core, CE envisions a system where products and materials are kept in circulation through design and corporate actions that eliminate or reduce waste, pollution, and negative environmental impacts. By decoupling economic activity from the consumption of resources, CE can address global environmental challenges, in addition to protecting the earth's resources and geodiversity for future generations. (UNDP, 2023) Product design is key to circularity as its influence extends over the entire life cycle of the product starting from simplification of design, types and amount of materials and resources used, the energy used and how the product lifetime can be extended at its end-of-life.

Circularity related standards are important to guide products, solutions and businesses in their journey towards CE and to have common standardized methods to track progress. Standards provide a common framework for assessment, communication, and trustworthy & reliable exchange of information between stakeholders.

This paper explores the current standardization landscape mostly from the ICT sector perspective, analyzing relevant standards to identify gaps, similarities and differences in various standardization approaches. The aim is to clarify the relevance and applicability of these approaches to ICT products and organizations and help with ongoing and future standardization work.

2 Regulatory and standardization landscape

The regulatory and standardization activities in CE topics are increasing rapidly, which often makes it challenging to navigate. The European Union (EU) is a frontrunner in regulation in environmental sustainability and circularity. Europe has a goal to halve its Greenhouse gas (GHG) emissions by 2030, reach 90% reduction by 2040 and achieve climate neutrality by 2050 (European Commission, 2025). The transition to CE is a key factor to meet this goal (European Union, 2015). In 2015, the European Commission (EC) adopted its first Circular Economy Action Plan (CEAP 2015) to stimulate the transition towards CE, boost global competitiveness, sustainable economic growth and generate new jobs (European Commission, 2015).

Regulations often require standards to support their implementation, particularly in sustainability areas. For instance, the EC gives standardization requests to the European standardization organizations - CEN[1] CENELEC[2], and ETSI[3] - on specific aspects to support the assessment of compliance with the regulation. There are multiple global, regional, and sectoral standardization forums that have relatively good cooperation and collaboration (see Figure 1). Regulation defines the “essential requirements” whereas the standards define the “technical requirements” and how to assess the compliance to the “essential requirements” of the regulations.

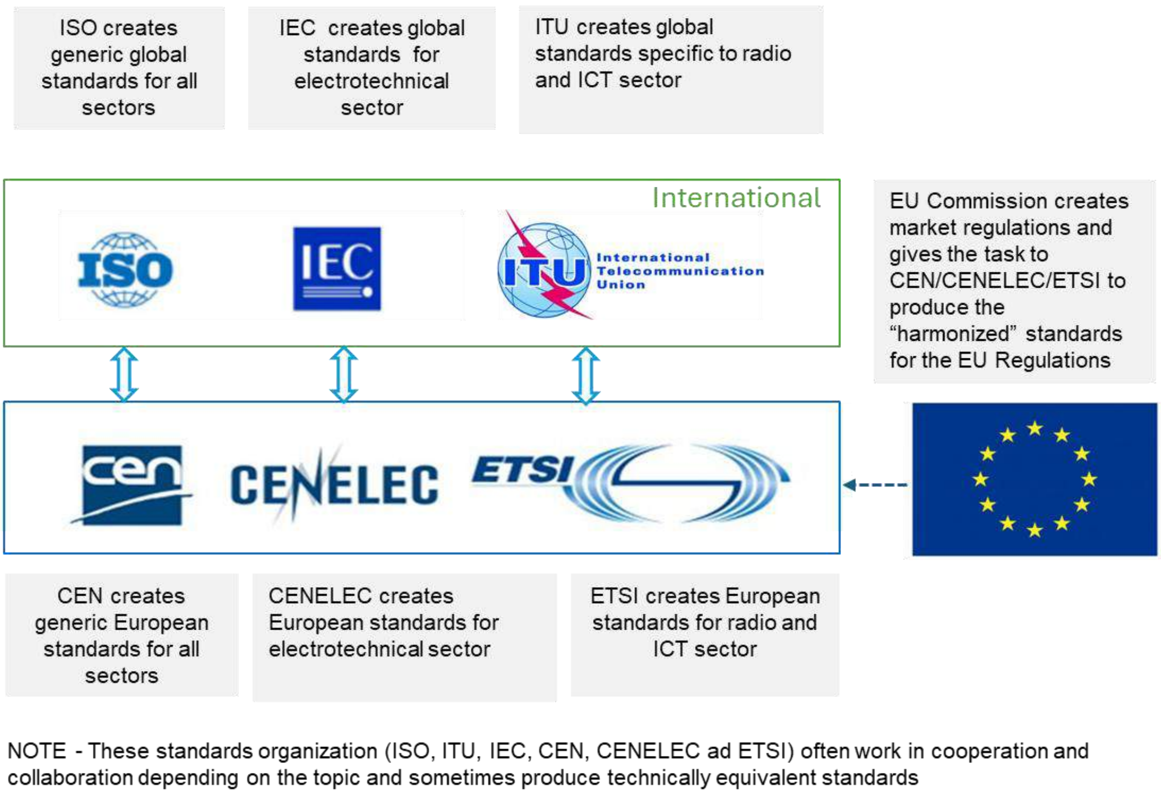

Figure 1 Example showing roles and connections between different standardization forums and market regulators.

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[1]CEN European Committee for Standardization

[2] CENELEC European Electrotechnical Committee for Standardization

[3]ETSI European Telecommunications Standards Institute

Standards cited in the EU Official Journal are called 'harmonized standards' and they are adopted to demonstrate compliance with the EU regulations/directives. Harmonized standards can originate either from EU offices or from the European standardization organizations. One example of harmonized standards from EU offices is European Sustainability Reporting Standards (ESRS). Since 2023, the Corporate Sustainability Reporting Directive (CSRD) regulation requires businesses of certain sizes in the EU to report on circularity-related selected indicators. Further, it requires businesses to identify CE related risks and opportunities, develop strategies, establish performance metrics, and implement data collection systems to track and improve performance based on the ESRS standard. (Official Journal of the European Union, 2023)

The ESRS sets clear and precise standards for corporate sustainability reporting as mandated by the CSRD framework. The ESRS E5 standard is about resource use and CE, and it requires companies to report aspects of circularity including impact, risk, opportunity management, metrics, targets and other entry specific information related to:

- Resource inflows, including resource use
- Resource outflows related to products and services
- Waste

(Official Journal of the European Union, 2023)

3 Circularity concepts

3.1 The Butterfly Diagram

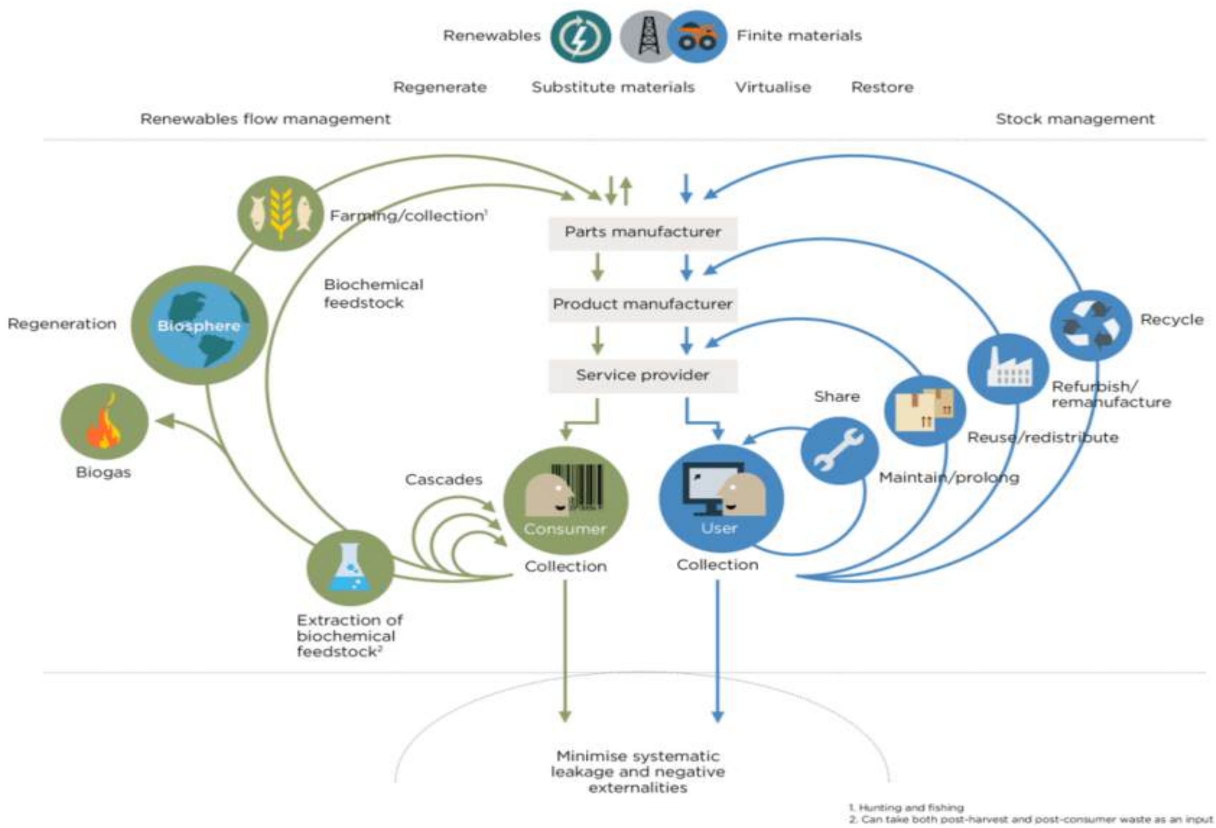

Figure 2 The CE Butterfly Diagram (Ellen McArthur Foundation, 2021)

On a high level, there are some commonly adopted principles on CE. The most famous is the "butterfly" picture (see Figure 2) from the Ellen McArthur (EM) Foundation, a non-profit organization committed to accelerating the transition to a CE (Ellen McArthur Foundation, 2021). The EM Foundation has played a significant role in popularizing and advancing the CE concept globally. The left side of the diagram is about the biological cycle of CE, processes such as biodegradation and composting which help to safely return nutrients back to the soil and regenerate nature. The right side of the diagram is about the technical cycle of CE, that encompasses the non-biogenic materials like metals, plastics, minerals and other synthetic materials which should be reused, repaired, refurbished and recycled since they cannot be safely returned to nature as soil nutrients to regenerate nature. This diagram has inspired many other concepts and even standards, as it is clearly visualizing this omplex topic and its relationships.

3.2 9R's

Another widely used concept is 9Rs (see Figure 3) which presents, in stack form, different aspects and their "ranking" or hierarchy in the circularity ladders. The hierarchy of the stack is based on the effectiveness of the strategies. The most effective strategies from a circularity perspective that have the highest ranking for smart creation and design are R0-R2 (Refuse, Rethink, Reduce) followed by strategies aiming to extend the lifespan of the products R3-R7 (Reuse, Repair, Refurbish, Remanufacture, Repurpose) and finally the lowest ranking strategies R8 and R9 (Recover, Recycle). (Potting, et al., 2017).

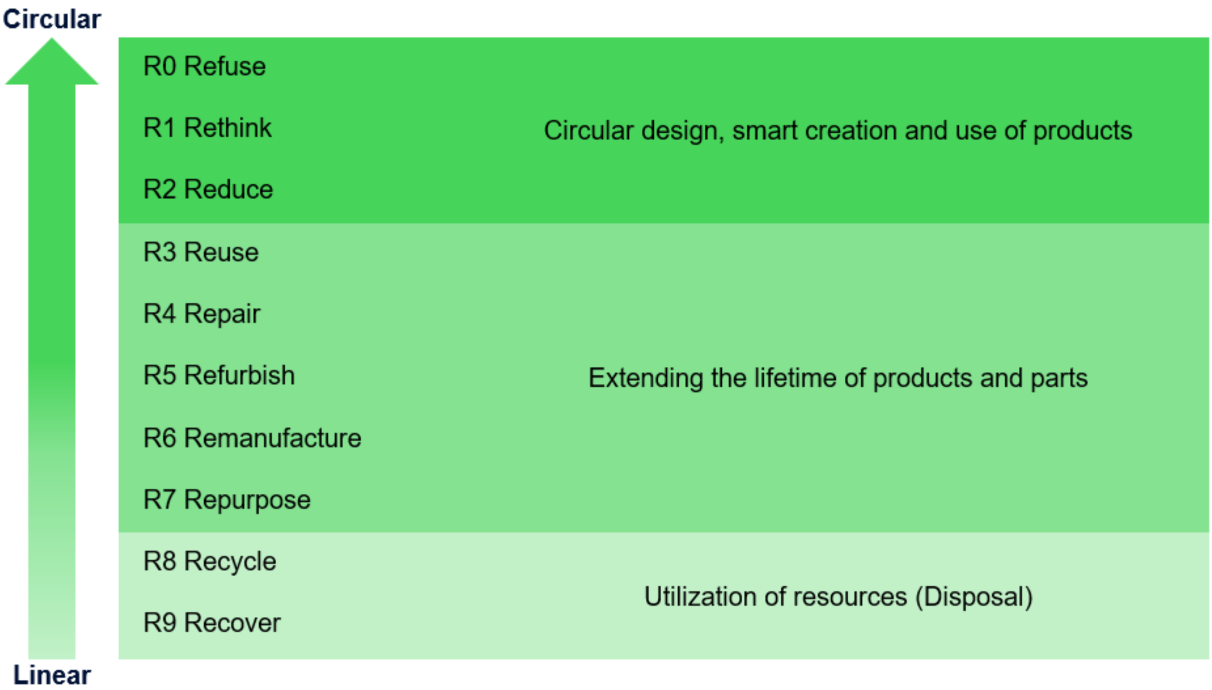

Figure 3 The 9R Circular Economy Framework (Potting, et al., 2017)

3.3 Material flow indicators

Material flow analysis — tracking the mass flow of materials — provides good insights on material circularity. Tools and indicators, like Circular Transition Indicators (CTI) developed by the World Business Council for Sustainable Development (WBCSD) and the Material Circularity Indicator (MCI) from the EM Foundation, complement standards from standards developing organizations (SDOs) and used by many companies. Many other methods are based on this concept; therefore, we introduce these two indicators here.

- CTI is a self-assessment process to determine circularity performance. It comes with an accompanying tool. These indicators focus on mass flow through the company and provide insights into overall resource use optimization, the link between circular material flows, and business performance based on quantity and intensity of circulation. They can be applied to both product and company levels.
- MCI tool is an Excel-based tool which includes the assessment of Inputs (what the product is made of and where those components come from) and Outputs (what happens at the end of

the product's life). This tool is helpful to assess and compare the scores of individual products and product portfolios, improve circular design decisions, and for internal reporting, communication and procurement decisions. The scores can be aggregated at company level. As of this year 2025, EM Foundation is no longer involved in the development of this tool. (Ellen MacArthur Foundation, 2015).

4 Circularity standardization landscape

Circularity standards can be categorized into foundational, product-level, organizational, and regional, as shown in Figure 4.

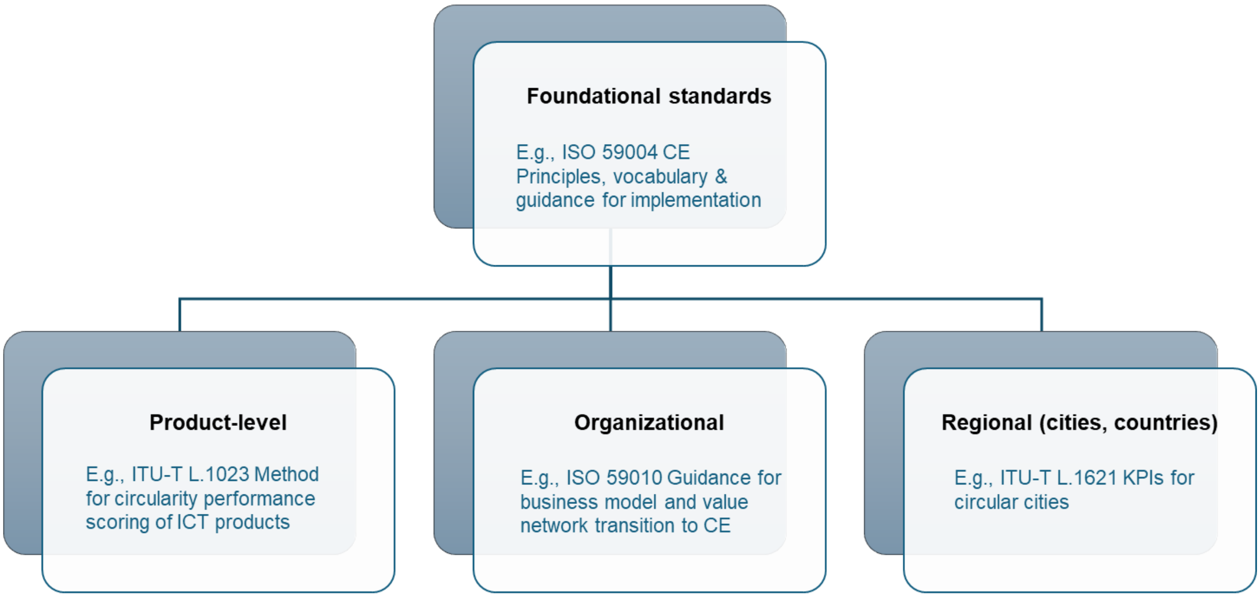

Figure 4 Categorization of circularity related standards

4.1 Foundational standards

Foundational standards provide overall principles, frameworks, vocabulary, and guidance for implementation. In 2024, ISO published the ISO 59000 series of standards which provide clear guidance for companies on how to transition to CE. From this series, ISO 59004 provides common vocabulary, principles, and guidance for implementation. The circularity principles presented in this standard are system thinking, value creation, value sharing, resource stewardship, resource traceability, and ecosystem resilience. It emphasizes considering these principles early in the design stage and throughout the product lifecycle. (ISO 59004, 2024).

4.2 Product-level standards

There are several ICT product-specific circularity standards and some non-ICT standards that are still applicable to ICT products. Some of the central and most widely known standards are introduced in the following sub-sections. [4]

4.2.1 EN 4555x series

Standards EN 45550-45559 from CEN/CENELEC are focused on material efficiency in response to an EC standardization request on defining and quantifying selected CE aspects. These are also applicable for ICT products. However, as these are horizontal standards, most of them do not provide detailed guidance on what aspects to consider while designing a circular product. For some of these aspects, sector specific vertical standards would be beneficial for more detailed guidance. The topics covered in these standards are shown in Figure 5.

[4] In addition to these, International Electrotechnical Commission (IEC) is also working on several standards focused on material efficiency, material declaration and material circularity-related aspects.

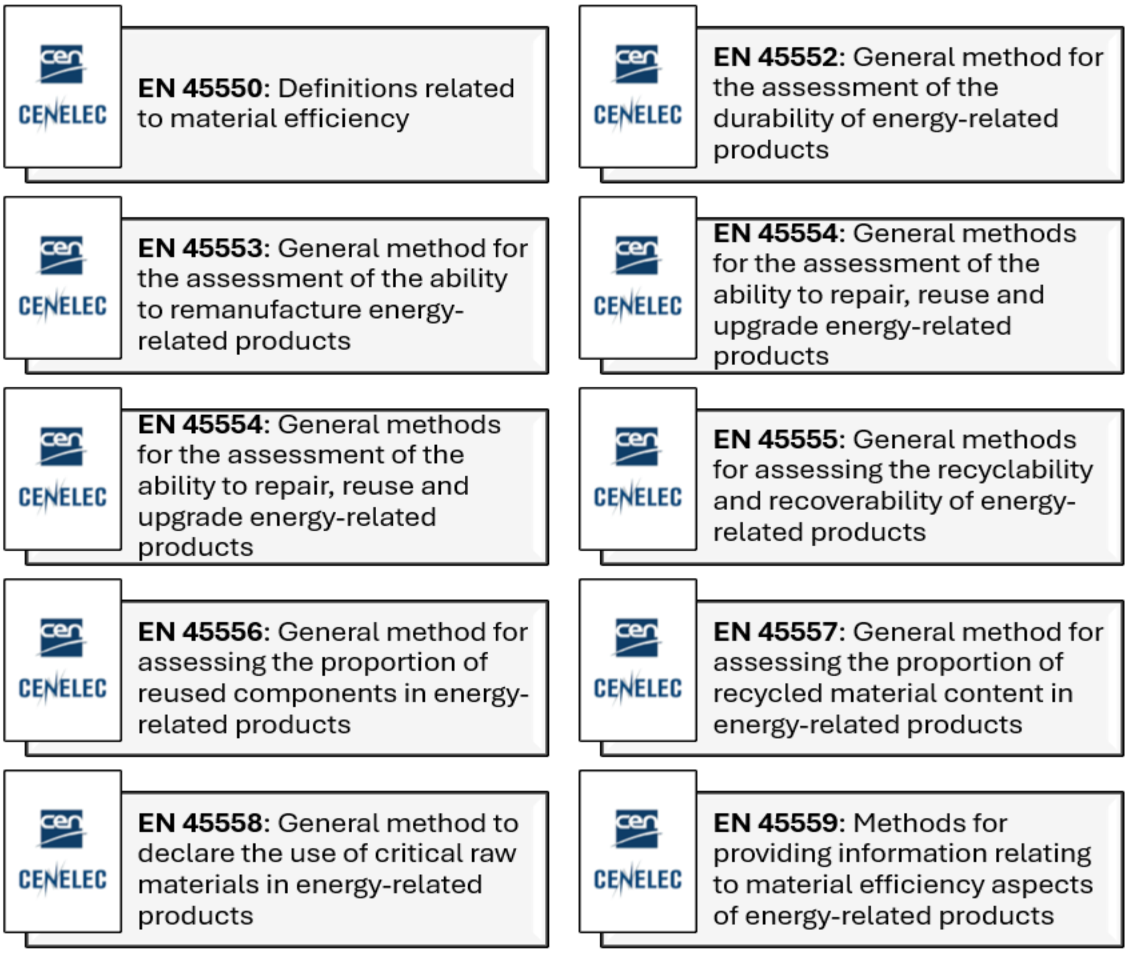

Figure 5 Scopes of EN 4555x standards

4.2.2 EN 45560 Method to achieve circular designs of products

Going beyond material efficiency, CEN/CENELEC recently published EN 45560 which:

- specifies requirements and guidance for integrating circularity into the design and development process of products and,
- supports the development of product design rules to fulfil the chosen circular business targets.

The core principle in this standard is life cycle thinking, as it provides guidance on how to reduce environmental impacts, and how to deal with challenges such as trade-offs during circular product design, without compromising other product functions including safety. (EN 45560, 2024)

4.2.3 ITU-T L.1023 Product circularity scoring

ITU-T L.1023 standard outlines an assessment method for circularity scoring of ICT products. It is focused on scoring one single product at a time. The assessment method consists of three steps:

1. Setting the relevance and applicability (R) of each indicator for circular product design for the ICT product at hand,
2. Assessing the margin of improvement (MI) of each indicator,
3. Calculating the circularity score based on Rs and MIs for the ICT product at hand.

The method rewards circular-designed ICT products with high % values and less circular-designed ICT products with low % values.

In this method, the different circularity aspects are grouped into product durability, equipment circularity, and manufacturer's ability to support the circularity of the products (see Figure 6). (ITU-T L.1023, 2023)

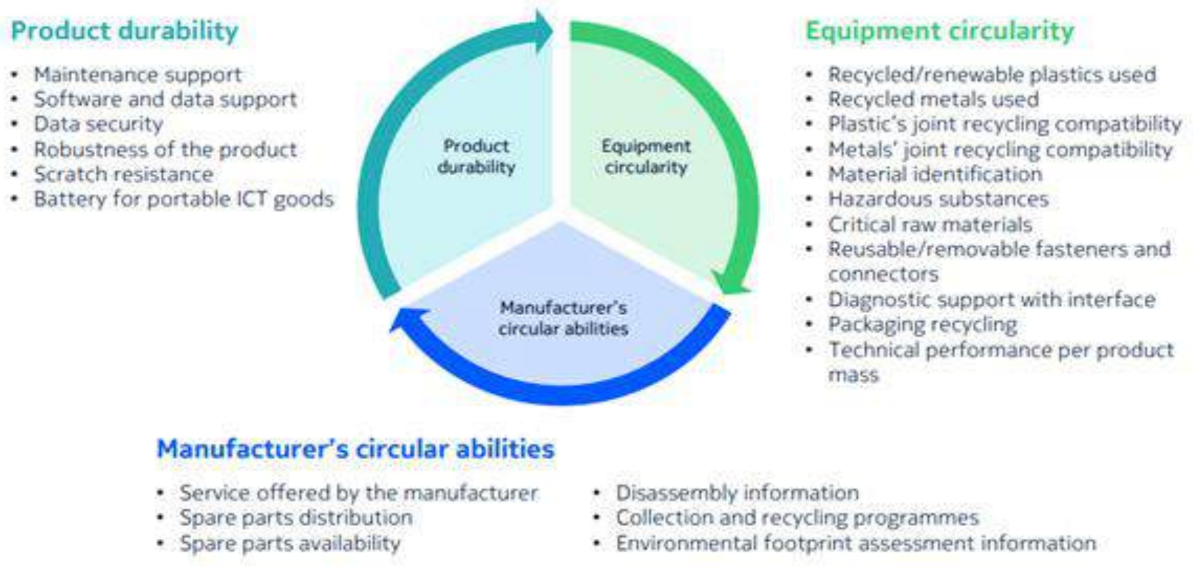

Figure 6 Aspects and indicators in L.1023 for assessment and improvement of product circularity, inspired by ITU-T L.1023 (2023)

The method in L.1023 should be used as a guideline for designers to assess the product design on the most relevant circularity indicators and to plan improvement based on the outcome. This method can be used as part of the procurement process. However, it needs to be noted that this method is not intended to compare products since assessment is subjective combining several different indicators or to separately use those indicators for reporting. (ITU-T L.1023, 2023).[5]

4.2.4 LCA standards

Life cycle assessment (LCA) is a well-established methodology for assessing the lifetime environmental impact of a product from raw material acquisition through production and use until the end-of-life. It can be used to assess the impact of a product or service, including the effect of circularity. However, most of the traditional LCA standards assess the impact of limited circularity aspects like material recycling and repair. With the advancement in CE related practices in recent years, products can have multiple life cycles via refurbishment and reuse after their initial use. The latest revision of ITU-T L.1410 / ES 203 199[6] includes more detailed guidance on assessing the impact of circular processes such as refurbishment and reuse and supports extended operating lifetime with multiple life cycles. (ITU-T L.1410, 2024; ETSI, 2024).

4.3 Organizational standards

For organizational perspectives, there are two major circularity standards that were recently published: ISO 59000 series and ESRS E5 (see chapter 2). These and other organizational standards are usually not specific to the ICT sector, but applicable to any organization. ISO standards are global, whereas ESRS E5 is an EU regional standard focused on reporting. However, as ESRS is applicable to global companies operating in Europe, ESRS already has some global reach.

4.3.1 ISO 59000 series

The ISO 59000 series provides guidance to enhance the understanding of concepts and principles related to CE. Figure 7 shows the relevant 59000 series standards:

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[5] There are also other circularity related standards from ITU-T and ETSI, For example, product group specific (e.g., server, data storage), best practices, digital product passport, etc.

[6] LCA for ICT products, networks and services

- Foundational standard ISO 59004 was described earlier in section 4.1.
- ISO 59010 provides guidance on the transition of business models and value creation models from linear to circular which involves the rationale for circularity, setting goals, determining strategy, reviewing, monitoring and continual improvement. (ISO 59010, 2024)
- ISO 59020 helps organizations[7] by specifying requirements and providing guidance for measuring and assessing their circularity performance. Key indicators such as resource inflows (reused, recycled, renewable content) and resource outflows (reused products, recycled materials) and other additional indicators for energy, water, and economic factors are provided. Many of these indicators have already been introduced by other circularity assessment methodologies like CTI (see section 3.3).

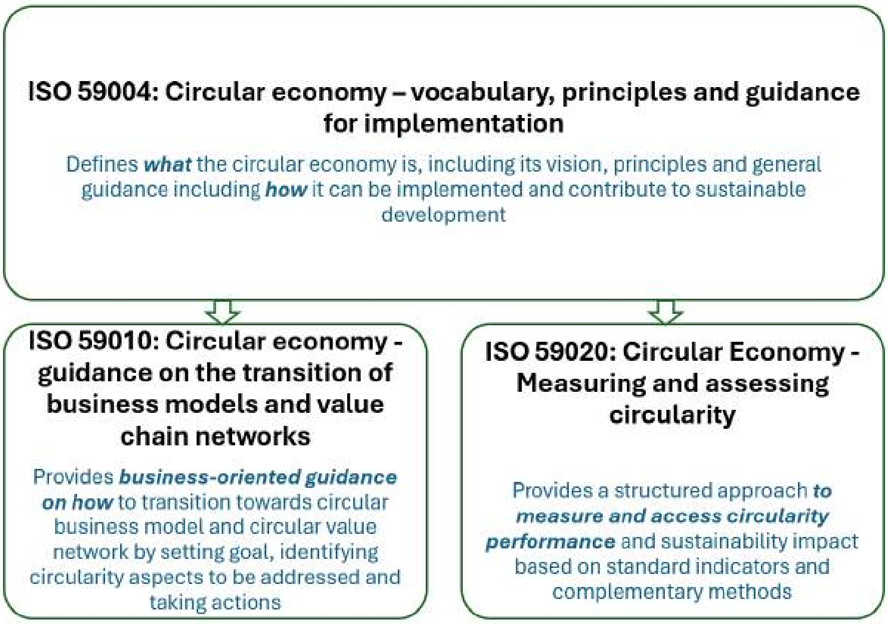

Figure 7 ISO 59000 series standards (inspired by ISO 59004, 2024)

ISO 59020 is one of the first major global standards providing good guidance for tracking performance and improvement. It offers a range of mandatory and optional indicators, enabling organizations to customize their reporting to align with their unique circumstances and priority areas. Such adaptability is valuable for some aspects when representing the entirety of an organization's impact or when initiatives cannot be condensed into a single indicator. (ISO 59020, 2024).

There are some similarities between ESRS E5 and ISO 59020 and they can be used to complement each other. E.g., ISO 59020 provides a measurement and assessment framework that might be helpful for ESRS E5, which is more focused on reporting. (European Commission, 2023).

4.3.2 Global Circularity Protocol

A new initiative -The Global Circularity Protocol (GCP) for Business has been initiated by WBCSD with the One Planet network. Like the GHG Protocol, which is credible and most widely used for GHG accounting, GCP aims to provide companies with a standardized, science-based approach to target-setting, measuring, reporting, and disclosing circularity and resource efficiency performance. The circularity performance assessment and management in GCP is planned to be based on CTI. (WBCSD, 2024) This initiative is a noteworthy development which merits monitoring.

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[7] ISO 59020 is applicable in multiple levels including product, organizational, inter-organizational and regional.

4.4 Regional standards

Product-level and organizational standards focus on micro-level circularity, while other perspectives, such as meso-level (e.g., sector, industries, industrial parks and cities) and macro level (national and other wide regional groups such as the EU) also exist. These are interrelated as the changes in product level will have effects on organization up to the national economies. Examples of regional standards are ITU-T L.1620 Guide to circular cities and ITU-T L.1621 Key Performance Indicators for circular cities.

5 Analysis of circularity standards

5.1 Categorization for the analysis

For this analysis, we categorize the circularity assessment standards into three main areas based on their scope and focus: foundational, product-level and organizational. Within these main categories, the following sub-categories were used:

- Design and concept: standards assessing wider principles and strategies of CE, like 9Rs, system thinking, design, value creation, value sharing, and resilience
- Circularity score and indicators
- Circularity effect: Assessing the secondary effects of circularity

Table 1 and Figure 8 map some of the main circularity assessment standards to these categories and sub-categories together with some additional information about the standards.

Table 4 High-level mapping of some main circularity assessment standards

Standard	Scope & Focus	Key Features	Category and sub-category[8]	R-strategies considered	Assessment boundary
ISO 59004 (2024)	CE principles, vocabulary/ definitions & guidance for implementation	Six fundamental CE principles; expanded R-strategies; Guidance for implementation	Foundational	R0-R9[9] as guidance for resource management	Guidance[10] Life cycle perspective recommends including value chain
ISO 59010 (2024)	Guidance for business model and value network transition to CE	Based on 5-stage transition guidance: (1) setting goal and boundary (2) Determining circular strategy (3) Transitioning a value creation model to circularity (4) Transitioning a value network towards circularity (5) Reviewing and monitoring for continual improvement	Organizational Design and concept	R0-R9[6] as guidance for resource management	Guidance[10] Life cycle perspective recommends including the value chain
ISO 59020 (2024)	Measurement and assessment of circularity performance	Mandatory core indicators and optional indicators. Helps in assessing some social, environmental and economic impacts from organization's actions to achieve circularity	Organizational and Product-level Circularity score and indicators	R3-R9[6]	Product - Full life cycle Organization - Life cycle perspective recommends including the value chain[10]
ESRS E5 (2023)	European Sustainability Reporting Standards, E5 Resource use and CE	Part of CSRD linked standard on resource efficiency, waste, CE	Organizational Circularity effect [11]	R3-R9	Own organization, focused on reporting

[8]Some standards (e.g., ESRS E5 and EN 45560) can be categorized into multiple sub-categories. This table only lists one major sub-category for simplicity.

[9]R0-R2 is covered in some of these standards as guidance for design strategies and resource management mostly on high level, not as circularity assessment methodology or as indicators.

[10]Upstream and downstream value chain recommended but no clear assessment guidance

[11]Requires also reporting KPIs even though no detailed guidance for the assessment.

CEN/ CENELEC EN 4555x Series (2019-2020)	Horizontal standards for energy related products focused on material efficiency, lifetime extension, durability, R'bility[12], recycled content, reused components, CRMs	See section 4.2.1	Product-level Circularity score and indicators	R3-R9	Each standard is focused on specific life cycle stages and specific aspects of circularity[13]
CEN/ CENELEC EN 45560 (2024)	Method to achieve circular designs of products	Supports journey towards circularity and measure it using KPIs	Product-level and Organizational Design and concept[14]	R3-R9	Product - Full life cycle Organization - Own Organization
ITU-T L.1023 (2023)	Assessment method for circularity scoring of ICT products	See section 4.2.3	Product-level Circularity score and indicators	R3-R9	Full life cycle
ITU-T L.1410 (2024)	Framework and guidance for ICT sector for LCA	See section 4.2.4	Product-level Circularity effect	R3-R9	Full life cycle

[12]Recyclability, reusability, refurbish-ability, remanufacturability, repairability, recoverability etc.

[13]For example, EN 45557 is about recycled material content, hence focused on raw material acquisition stage.

[14]Provides also KPIs to measure and set targets for the circular transitions.

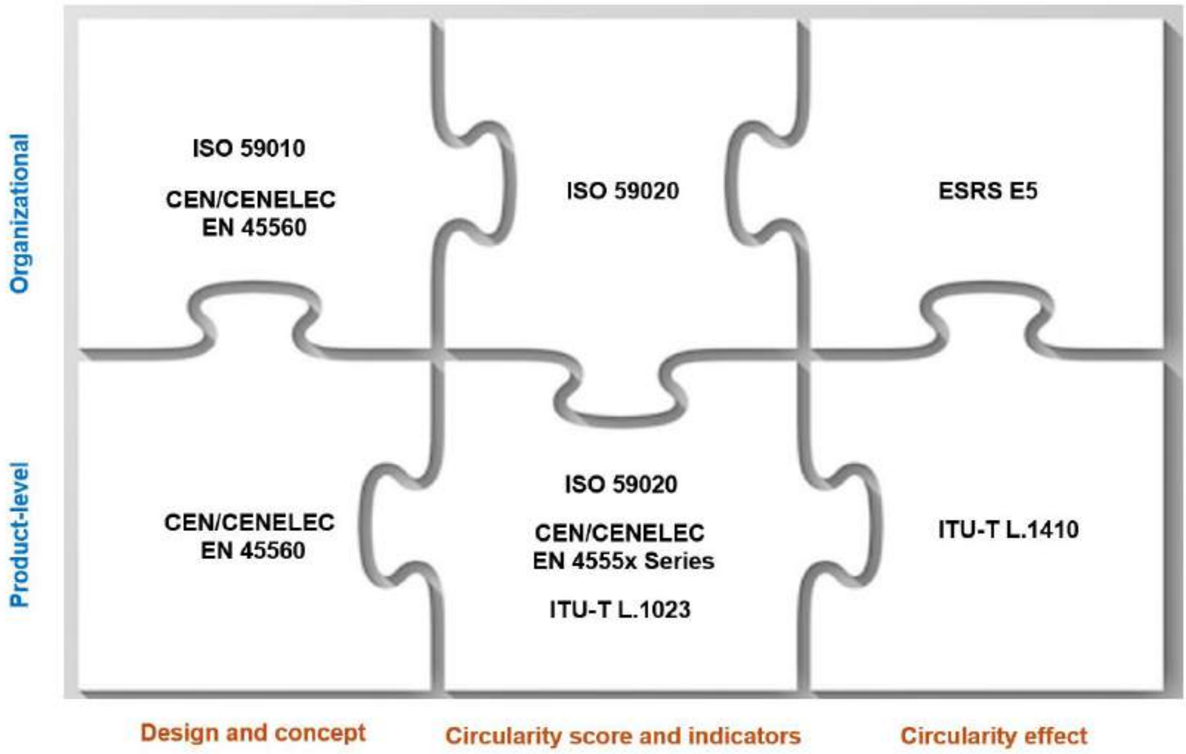

Figure 8 Categorization of selected circularity standards

5.2 Main findings from the analysis

While analyzing these circularity standards, the following points were identified:

1. Coverage of the standards differ.
2. Definitions vary.
3. Methodologies are heterogeneous.
4. Limited guidance on assessment beyond own organizational boundary
5. Lower-circularity R-strategies dominate.

In the following sub-sections, we will describe these findings in more detail.

5.2.1 Coverage of standards

As can be seen from Figure 8, the analyzed standards have different dedicated scopes. Combining different perspectives from different standards and considering trade-offs and limitations will give a wider and more holistic view. For assessing the environmental impact of the circularity actions and solutions, LCA standard needs to be applied.

5.2.2 Definitions alignment

Clear and concise terminology is a fundamental starting point for establishing common language, defining requirements, information exchange, collaboration and interoperability. Kirchherr, et al (2017) identified and gathered 114 definitions of CE for their analysis and highlighted the wider variability in understanding and interpretation of CE concept. Even in standards, parallel development of different circularity standards in different standardization forums results in different definitions creating confusion and fragmentation. Figure 9 shows an example of CE definitions from three major standards.

Circular Economy definition from **ISO 59004: 2024**	**Circular Economy** definition from **ITU-T L.1071: 2024**	**Circular Economy** definition from **CEN/CENELEC EN 45560:2024**
Economic system that uses a systemic approach to maintain a circular flow of resources, by recovering, retaining or adding to their value, while contributing to sustainable development. *Note 1 to entry: Resources can be considered concerning both stocks and flows.* *Note 2 to entry: The inflow of virgin resources is kept as low as possible, and the circular flow of resources is kept as closed as possible to minimize waste, losses and releases from the economic system.*	**An economy closing the loop between different life cycles through design and corporate actions/practices that enable activities like reuse, refurbishment, remanufacture and recycling in order to use raw materials, goods and waste in a sustainable and efficient way.** *NOTE 1 – The circular economy concept distinguishes between technical and biological cycles, the circular economy is a continuous, positive development cycle. It preserves and enhances natural capital, optimizes resource yields, and minimizes system risks by managing finite stocks and renewable flows, while reducing waste streams.* *NOTE 2 – Definition adapted from [b-ITU-T L.1022], [b-ITU-T L.1020] and [b-ITU-T L.1604].*	**Economic system that uses a systemic approach to circulate products and materials at highest value for as long as possible by aiming to eliminate waste and pollution, while contributing to sustainable development and giving the opportunity for natural systems to regenerate themselves.** *Note 1 to entry: The inflow of primary material is kept as low as possible. [SOURCE: IEC 60050-193:20242 (IEV 193-01-01)]*

Figure 9 Example of different CE definitions

Universally harmonized definitions are missing also for some other key terms, like refurbishment. This adds to the complexity for business and governments to assess the impact, compare the progress, and align regulatory requirements with targeted initiatives and allocation of investments. Common terminology would help consumers and businesses to make informed, conscious decisions based on reliable and understandable data.

As a starting point, it would be beneficial to have one definition for CE which everyone would use. A subsequent step would be harmonization of other key terms related to CE.

5.2.3 Methodological heterogeneity

A wide array of standards already exists for assessing circularity from both product and organizational perspective. Numerous stakeholders, including standards development organizations, academic institutions, research bodies, and other entities, are engaged in advancing work in this field. Indicators based on resource inflow and outflow are well aligned across assessment standards and frameworks, although they sometimes use different wording or approaches for similar concepts. An example of aligned approaches is the ITU-T L.1023 Product circularity scoring which uses aspects defined in EN 4555x series standards. In the development of future standards, it is important to ensure that methodologies are aligned between the different SDOs and standards to avoid fragmentation.

5.2.4 Assessment boundary

Current organizational CE standards often lack a full value chain perspective in assessment methodologies. Unlike the product perspective which mostly seemed to cover the full life cycle and GHG emissions reporting e.g., GHG Protocol Scopes 1, 2, and 3 approach, the focus of most of the current organizational circularity standards is within its own organization and do not provide clear guidance or methodology for assessment of circularity aspects in the value chain activities which are outside organization's operating boundaries or direct control. This is true for both upstream and downstream activities. The recently published ISO 59000 series introduced good high-level guidance and recommends considering upstream and downstream value chain, however, the assessment methodology and indicators for tracking these processes are very limited. These challenges could potentially disincentivize innovation, improvement in circularity and reward circular supply chain and circular use. Therefore, it would be beneficial to have clearer guidance and methodological development in future standards to enhance circularity assessment and reporting beyond the company's operational boundaries. This could encourage and motivate value chain actors to collaborate and push each other to improve the whole value chain, rather than focusing only on their own operations and transferring responsibilities to other parties in the value chain.

5.2.5 Higher value retention

While the CE framework is increasingly used to guide sustainable production and consumption, current assessment standards, as well as company actions, often exhibit a narrow focus on lifetime extensions and material flow metrics, such as recycling rates, input-output analysis, or resource recovery efficiency. This approach, while valuable, tends to emphasize lower-circularity R-strategies and under-represents higher-value circularity strategies, like Refuse, Rethink, and Reduce that focus on the upfront assessment of products and resources needs and on re-designing products, services, processes, business models and other approaches. R0-R2 strategies are currently covered in existing standards mostly as guidance for design strategies and resource management and are at too high level focusing on reducing the inflow of materials. However, CE assessment tools and standards frequently fail to capture the systemic, design-driven interventions represented by these higher-circularity strategies. As such, there is a pressing need to broaden CE assessment methodologies to holistically include wider R-strategies, particularly those that enable a shift towards sufficiency[15] and value retention rather than merely end-of-life resource recovery.

6 Summary and conclusions

This paper explored the current standardization landscape and analyzed key standards highlighting potential gaps and inconsistencies. While the focus was on the ICT sector, the findings are applicable to any sector. As the standardization landscape for CE is complex, this paper also provides categorization of current standards to make it easier to navigate.

Several circularity standards are already available depending on the assessment scope and needs both for organizational and product circularity assessment, ranging from design and concept, circularity score & indicators, and standards assessing the secondary effect of circularity. A holistic perspective requires utilizing multiple circularity standards on different categories, considering their trade-offs and limitations.

The analysis revealed several areas for improvement in existing and future circularity standards and their implementation.

- First, universally harmonized definitions, consistent methodologies, and metrics would aid companies and governments to assess the impact, compare progress, align the regulatory system with initiatives, allocate investments and for customers to make informed decisions based on clear and reliable data.
- Second, clear guidance for assessment and indicators beyond company boundaries akin to GHG Scope 3 reporting can drive value chain-wide collaboration, help to avoid transferring the responsibility to other parties in the value chain and support innovation and improvement in circularity.
- Third, future standards could better capture the higher order R-strategies from the circularity ladders beyond lifetime extension and material flows. The ability to assess the high value principles and strategies (R0-R2) are important to improve recognition of systematic change and design-led value-retaining interventions for enhancing circularity. Further research into weighing the impact of different circularity strategies (9Rs) for the complete circularity repertoire would be beneficial.

The dynamic nature of the CE, technological advancements in ICT sector, regulatory shifts, and evolving industry best practices necessitate continuous improvement of relevant standards as well as publication of new standards in coming years. The findings presented in this paper are provided for further research and development in CE standardization as it continues.

[15]Sufficiency is about avoiding or reducing the demand for materials and resources while delivering human wellbeing for all within planetary boundaries, *definition based on IPCC* (2022)

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Design for Degrowth- Wardrobe Analysis to Inform a New Business Lease Model in Fashion and Clothing

Nicola Mansfield

Senior Lecturer

University of Westminster

United Kingdom

Abstract

Durability in garments is a nuanced idea explored in the fashion industry through the technical testing of garments supported by third-party practitioners in laboratories in a siloed institution. These processes are evaluated in a retail head office, and the results are used to demonstrate aspects of the garment's durability.

This concept of durability will be explored by auditing customers' wardrobes to explore those items that have both physical and emotional durability, the intention is to produce a business model. It has been said that the price paid for a garment is quickly forgotten. (Niinimäki K.2013) after it has been owned for several years.

In a degrowth society, there is a need to explore these attributes and how product developers can ensure their garments meet requirements: they are loved longer and last longer in people's wardrobes and promote long-term sustainability. The area of consumer wardrobe audit and archival research will consider the attachment styles to artefacts, using action research based on an attitude scale linked to clothing items.

This work explores fashion archetypes as identified in the primary research, formulating a new business model which matches product to user. Noting products and emotional durability, this offers new methods of consumer engagement whereby their future use of clothing is accounted for. This will enable multiple user lifetimes as discussed by Kate Fletcher in Opening up the wardrobe (Fletcher K., & Klepp, I.G. 2017).

Introduction

Background, context and rationale

This paper will explore archival garments and fabric with an attachment and attitude scale and realistic thinking about the durability applied with technical knowledge of design for longevity.

The central aim of this research is to explore how garments endure over time, both physically and emotionally, and how these insights can inform sustainable fashion design and businesses.

Developing a business model to promote garment longevity across emotional, material, and economic dimensions.

Literature review

Product longevity

Product longevity is a key concern in sustainable fashion. Planned obsolescence, especially in fast fashion, reduces garment lifespan and encourages frequent repurchasing. Research presented by (SCAP 2017) highlighted differing design strategies between departments. While children's wear designers considered durability and reuse, women's fashion designers often neglected these factors, despite high environmental awareness. (Local Wisdom 2017) emphasised that although brands control production, it is the consumer who determines post-purchase use, which can either reinforce or undermine sustainable values.

The concept of product life extension, discussed by (Goworek et al. 2013), reflects efforts by consumers to repair or repurpose garments. However, repair was often stigmatised, with repaired clothes being relegated to low-status activities, this has turned a corner with new business models such as (Sojo 2025) and (The Denim Doctor 2025). Emotional attachment to garments can encourage repair, demonstrating that value perception can influence post-purchase behaviour.

Design for Durability

Designing for durability presents another approach to reducing waste. However, fast fashion trends and social media-driven consumption particularly among Millennials and Gen Z—often discourage repeated wear (Gomes De Sousa, M. 2020). Rental Platforms like Hurr Collective offer alternatives by allowing consumers to rent rather than buy occasion-specific clothing. This rental model provides a temporary fashion solution and reduces demand for new garments (Hurr 2025).

Dunne noted that wardrobe studies often exclude items kept solely for emotional reasons. This suggests a gap in understanding the full scope of garment use and storage. The concept of workwear, for example, is increasingly fluid. Remote work and digital communication have transformed traditional dress codes, raising new questions about what constitutes active wardrobe use. (Dunne, Zhang, and Terrine 2012)

The issue of fast fashion's planned obsolescence is exemplified by a finding in Fashion Theory (Annamaa et al., 2012) that many garments are not expected to last beyond ten washes. This undermines sustainability goals, even among consumers who express environmental concerns. (Jackson and Shaw 2009) observed a disconnect between environmental awareness and actual purchasing behavior.

High-end brands like Patagonia, Nudie Jeans, and Burberry have adopted slow fashion models, promoting longevity and investment in quality. In the recent report for Ellen MacArthur foundation this work has been extended across denim products. (Ellenmacarthurfoundation2023),

A prediction by (Poldner 2013) was that environmental consciousness would become mainstream by 2023, yet consumption is still growing. Assessment tools, like the Sustainable Apparel Index, aims to quantify a garment's environmental impact, including CO2 emissions and water usage. However, these tools often focus on production and overlook usage and disposal phases (Common Objective 2025).

Wardrobe studies by (Klepp and Laitala 2015) involved interviewing participants about retired garments, analyzing both user perceptions and physical wear. Their findings indicated that clothing habits and wardrobe longevity are strongly linked to garment attributes, including fit, style, and quality, which includes manufacture and fabric properties.

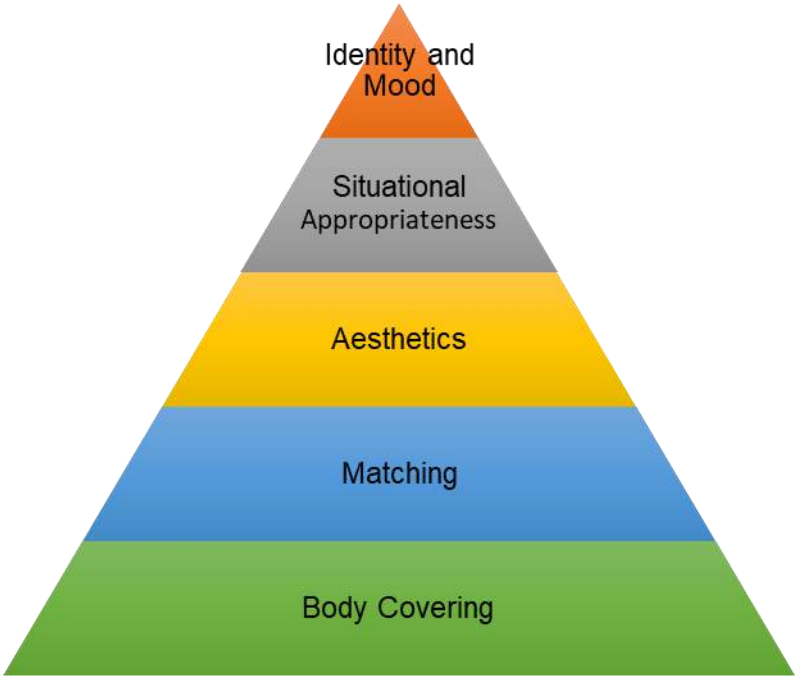
Snyder and Fromkin adapted Maslow's idea of self-actualization and applied it to dress; they argue that consumers seek uniqueness through distinctive clothing. Ironically, this can accelerate obsolescence when trends fade, or an item loses its uniqueness (Snyder and Fromkin 1980). Workwear authors Johnson Gross and Stone encouraged consumers to edit wardrobes ruthlessly, removing garments that no longer fit, flatter, or align with lifestyle needs. Their "six-month rule" suggests decluttering clothes not worn within that period, promoting more thoughtful wardrobe management, this can lead to generation of significant waste. (Johnson Gross and Stone 1996)

Fashion archetypes like the boiler suit, dungaree, and apron demonstrate durability and functionality. (Toscani 2009) highlighted how these designs have transitioned into everyday fashion, thanks to their practical construction, durable fabrics, and adjustable features. Such garments may inspire future design efforts aimed at longevity and versatility.

Emotional Attachment

Comfortable clothing with generous fits has become preferred, especially among older consumers. (Cotter 2017) found that many people retain clothes that no longer fit due to emotional attachment, though relaxed-fit garments are more likely to remain in use. Fastenings like elastic waists and pull-on styles accommodate weight fluctuations, contributing to garment longevity. Petersson discusses this in 2021, discussing the joy and distress of consumption, emotional bonds are formed and applying affect theory can distinguish the complex relationships that consumers have with their clothes (Petersson 2021)

(Thurston et al.1990) warned against overly fashionable clothing, noting that it can hinder professional perceptions. Dunne's situational appropriateness model reinforces this idea Figure 1, suggesting that moderation in style contributes to longer garment use.

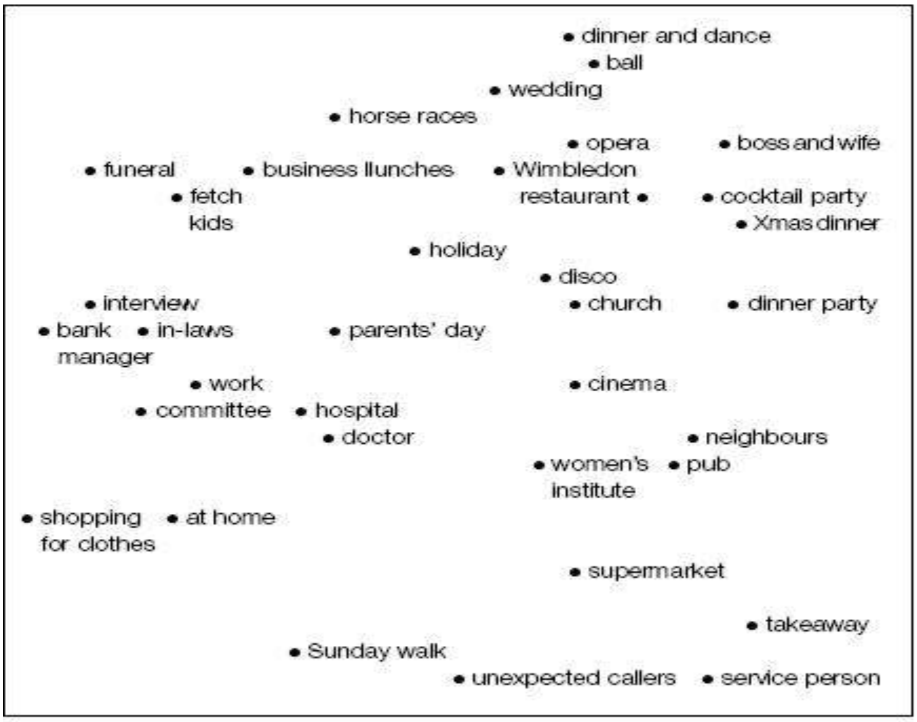


Dunne's situational appropriateness model

Figure: 1 Dunne L.E. 2012

Wardrobes composed of well-fitting, moderately fashionable items are likely to be used more regularly and retained longer. Although the social appropriateness and coded rules Fig 2 for perceptions of what is acceptable in the workplace has changed over time. Highlighted in the model scatter diagram below, this was explored by (Tseëlon2012) and (Niinimäki, 2013). looking at how frequency and visibility contribute to clothing wear.

This has been further supported by (Guy D. 2020) and informed design practices, particularly in menswear. This involves buying clothes that last and creating emotional durability, combining the physical and emotional attributes a garment represents. (Chapman J 2015). This might constitute an outfit they always rely on, can be worn for any occasion, linking to social appropriateness and increases in appreciation the more it is worn. (Coren M 2023). Chapman also discusses waste as a sign of a failed relationship with that item, this has been explored by (Neto & Ferrera 2023) which acknowledges friendship attributes in the connection to clothing, keeping a faithful item that will not let you down. Nostalgic elements play a part in attachment too, keeping items as a fashion history of the wearer connected to milestones and events in the wearers mind. This can be overwhelming and participants in the study by (Mellander and McIntyre 2020) expressed both anxiety and joy in the contents of the whole of their wardrobes.



Legend: The top left corner (e.g. going to the races, funeral and fetching kids) indicates a space of high visibility. The bottom right hand corner (e.g. going to the local takeaway, answering the door to a service person or unexpected stranger) indicates a space of low visibility.

Figure 2: A Multidimensional Map of Social Situations According to their Clothing Concerns (adapted from (Tseëlon, 1995) (Niiniimaki 2013)

Studies by (Goworek et al. 2013) found that consumers often downgrade clothing for lower-status tasks like cleaning or gardening rather than disposing of them outright. This behavior reflects a form of sustainability that deserves more attention. Though these garments are no longer "fashionable," they continue to serve functional purposes, extending their lifecycle and reducing waste. Finally, a strong sense of personal style indicates that some consumers are led not by trend but by their own chosen sense of dress, what is socially appropriate and the desire to show their personal meaning through clothes. (Martinez 2024).

Fabric durability and planned obsolescence

Jackson and Shaw discuss the notion of planned obsolescence with brands looking at under 10 washes before the breakdown of garment (Jackson and Shaw 2009). In the Jeanologia report, commissioned by the Ellen McArthur foundation (Ellenmacarthurfoundation2023), the desired durability was above 30 washes of jeans, and a few brands were working at 35 washes. The detail of fabric performance and the landscape of textile testing was explored in more detail, noting that the historic use of up to 22 test methods has reduced to between 1- 7 tests. These were the most common durability tests as well as the wash tests, by fashion businesses.

- tear strength
- tensile strength
- dimensional stability,
- abrasion resistance
- colour fastness

In this report jeans across fashion brands were compared for their level of durability, and it revealed stark inconsistences in quality. These factors also linked to weight and fibre composition of the items and recommendations that can lead to excellent longevity in the wardrobes of consumers.

In reviewing this data there is an opportunity to build durability into business models. This was explored by (Platts S. 2025) in this panel discussion at the Source trade show on de -growth models and the notion of buying less and better, the panel explored the myth that volume and profit are connected, sustainable, steady growth is often more beneficial. Developing product that is emotionally durable, and a longer-term investment can also reap rewards.

Methodology

This methodology is situated within the broader context of action research and participatory qualitative inquiry supporting iterative knowledge generation through consumer engagement thoughts, feelings, and actions in relation to clothing (Reason & Bradbury, 2013).

This study adopts a qualitative, interpretivist approach to explore consumer emotional attachment to garments and the longevity of clothing items. Interpretivism, as described by (Saunders et al. 2023) and (Bell et al. 2024), is appropriate for understanding complex, subjective experiences. Emotional connections to clothing are highly personal and context-specific, making interpretivism suitable for capturing nuanced consumer perspectives (Fleetwood-Smith et al., 2019; McIntyre, 2019; Mellander et al., 2022; Errázuriz et al., 2022).

Inductive approaches analyse information from specific instances or participants to formulate a theory, (Saunders et al., 2023; Bell et al., 2024). Due to its reliance on subjective interpretations, inductive approaches are typically informed by interpretivist philosophies, as exemplified in this research design (Saunders et al., 2023).

The primary data collection methods are wardrobe audits and semi-structured interviews; both aimed at producing in-depth qualitative data on consumer experiences with garments. Wardrobe audits will require participants to review their clothing items and assess emotional attachment using a Likert scale adapted from Sanders (2010), which measures the degree of emotive versus neutral sentiment toward each garment. Additionally, the audits will evaluate garment longevity, fabric composition, and construction quality. Industry-standard textile durability assessments such as those used by (Intertek 2025) will be referenced to explore fabric performance.

Semi-structured interviews will follow the “active interviewing” model proposed by (Holstein and Gubrium 2003), encouraging open, conversational engagement. This technique fosters honest and reflective responses around themes such as garment attachment, wardrobe behaviour, and product longevity. Interview data will be transcribed and analysed using thematic analysis to identify recurring patterns and meanings (Dawson, 2019; Saunders et al., 2023).

Focus groups have not been selected due to practical limitations, including participants' geographic dispersion, scheduling challenges, and the need for confidentiality when discussing personal wardrobes. Individual interviews are more appropriate for exploring the intimate and private nature of clothing relationships.

To ensure validity and reliability, the study incorporates bias mitigation techniques based on (Kelley 1999), including pre-testing instruments, training interviewers to avoid leading questions, employing forced-choice and reverse-scored items, and seeking diverse participant representation. These measures aim to minimise response, selection, and researcher bias.

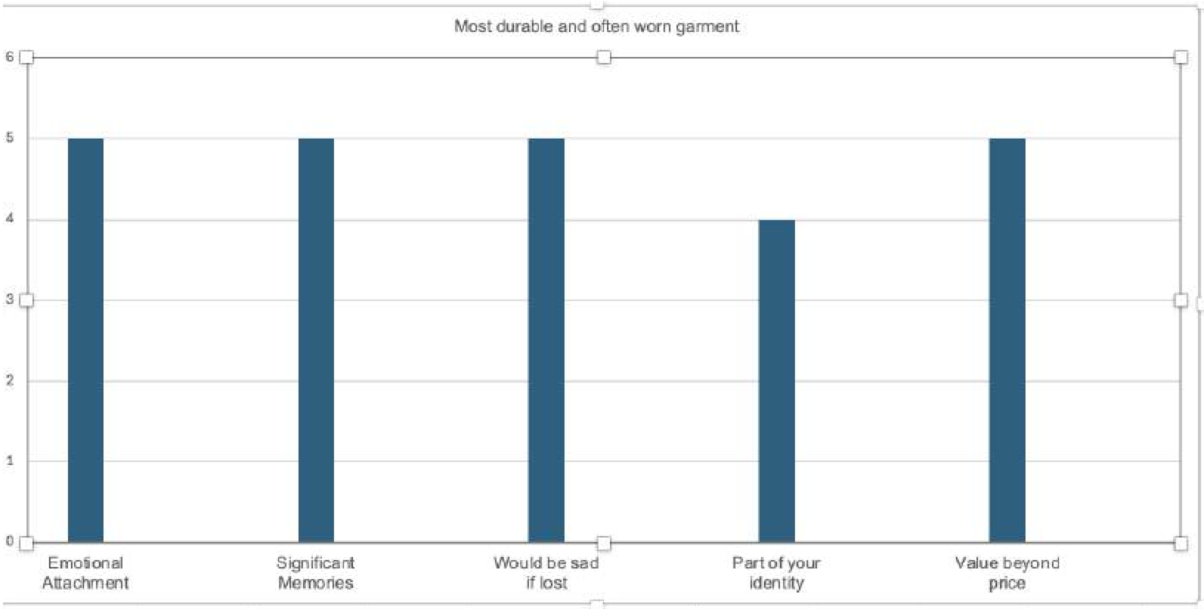
In summary, the study employs an interpretivist and inductive methodology to explore how consumers relate to garments emotionally and materially. Through wardrobe audits and individual interviews, this research aims to generate meaningful, participant-driven insights into the lifecycle and attachment behaviours surrounding clothing.

Results & Discussion

In depth wardrobe audits were carried out with the pre- selected participants, all female and from either ends of the age spectrum. The interviewees were above 70 years of age and also between 20-30 years old. This gave a broader understanding of the results. It is significant that the younger respondents did assert that they had not fully developed a personal style or identity. This corresponds to fast trend uptake in younger generations. They had all formed strong bonds with the items, especially those that no longer fit but were kept anyway. This tied in with life events, such as confirmation, leavers prom, festivals and event and occasion wear featured significantly. In keeping these items, that were beyond their material worth, they kept the memories as a souvenir and would pass these on. This was qualified further that they would be given away only if the receiver was deemed worthy of receiving the garment.

More was deduced from the often worn and cherished items, 50 % of these were denim, a jacket and cargo jean, the other items were classic shirts and a classic pleated skirt. The value of the item might have initially been low, but in the users eyes the perfection was in the reliability and dependability. Notably one participant had replaced a jacket for the same item in a bigger size. One participant had stated these jeans were practical and comfortable replica of a former pair and were part of her identity and worn “as often as possible” (P 1). Participant 2 had altered the skirt to fit along the years she had owned it. A classic shirt which was a bit small, was planning to be replaced by P3, if they could find the exact same item. Figure 3.

Figure 3: Analysis of most durable garment out of 5 score



In terms of durability and fabric performance denim test benchmarks are discussed by the Ellenmacarthur report, all respondents had exceeded 30 wears and washes of these archetype items. Interestingly the younger participants were not certain these items represented their identity, they both stated they experimented with fashion to develop this ideal, the older women were certain of their fashion identity with a sense of fashion maturity.

The stages of emotional attachment witnessed were evaluated in the wardrobe audits through these stages. Strong emotional attachment was connected to a story behind the acquisition, although this was not always the case. If the item was a charity store find or in a value retailer that also provided an equal thrill, value or price was never a predominant factor linked. Attachment became strong early on the in the wearer’s relationship, through frequent wear and reliability and the item, even in occassionwear was revisited for many events.

Phase 1. The thrill of acquisition stage was mentioned by all the women and stories of how and when they bought the items and the adventures and events attended, were in evidence.

High frequency of use in the denim items was most apparent noting both durability of fabrics and a strong sense of personal identity with the jeans and jacket, both extremely durable and suitable for most social occasions. The wardrobe audit provided the data in Figure. 4. The exploration of the contents of the wardrobes explored changes in dress codes over time, as noted by (Tseëlon, 1995).

Nowadays noting that the former coded rules have changed over time, making casual clothing more frequently worn and suitable for many occasions, everyone surveyed would wear denim to the workplace. In this data review shown in the regression chart, the low frequency items were kept but if the 6 month rule was followed, there is a high likelihood they would become waste or resale.

With the dresses, both vintage Ossie Clarke, the opportunity to wear these often in different settings and revisiting the garment was viewed as this reliable friend as suggested by (Neto an Ferrera 2023). Both garments no longer fitted the wearer and were valuable, the attachment was so strong that these items would be kept forever as a retrospective memory.

Phase 2. Attachment stage

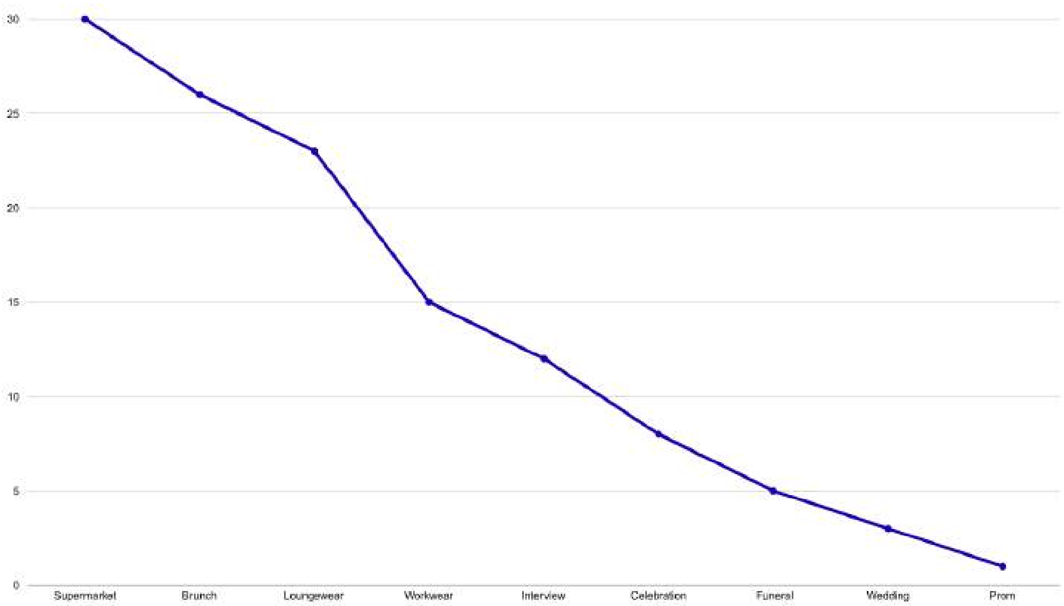


Figure 4:

Authors own - Clothing activity, social appropriateness and frequency of wear Regression chart 2025. Legend: Frequency of Wear - Occasion and social appropriateness

Phase 3. Usage stage. Frequency of wear could be the most important stage, and many items were worn frequently on rotation, these were emotionally durable products, the fashion archetypes. The analysis is shown in Figure 4, shows the new social appropriateness moved the original model (Niniimaki 2013).

With clothing being less formal the need for these occasion pieces has significantly diminished. Personal identity as demonstrated through clothing is strong with the older participants and formal occasions for the younger ones had involved rental and borrowing clothes.

Trend Fatigue and clothing discard stage were unlikely with the selected items on the attitude and attachment scale shown in Figure 3. They all expressed that these items would always be in their collections, and they would buy replicas, they all said they would replace these items.

Finisterre have started a lease scheme which would be a model that could be used to support the idea of eternal replacement.

The retrospective stage is explored with the two 50-year-old dresses from the 70's Designer Ossie Clarke, a potential market value of £1600 would not encourage the owners to part with these cherished clothes (Ebay 2025).

The stages are reflected in summary here:

Phase 1 Thrill and Acquisition Stage

Phase 2. Attachment stage

Phase 3. Usage stage

Phase 4 Fatigue/ Failure stage

Phase 5 The Discard stage

Phase 6 Retrospective stage

Business Case Opportunity

These phases are common to the Linear economy in fashion and to capitalise on the creation of design for longevity and degrowth, there is a need to consider decoupling purchasing and profit from new product. In the Source manufacturing trade show the panel discussed fewer garments but better products (Platts 2025).

This opens a possibility for a post growth model, which denim brands have a great opportunity to develop. Along with a vibrant 1st hand market for Denim resulting in 70 million pairs being sold each year (Draper's 2021). Levis also bought back second-hand products from the market for their own resale (Fashion United 2020). Ultimately, Levis are controlling the brand in both all user lifetimes and selling these items between $30 and $297 USD.

This model can be explored by similar brands with a lease scheme for denim, a lifetime subscription for items that will never leave wardrobes.

With customers creating strong personal style and having the benefit that denim has become socially appropriate for many occasions, this could result in another avenue to reduce growth, manage overconsumption and production as identified in SDG 12 (United Nations 2025).

Conclusion

The business model idea is to decouple identity from newness with a lease scheme for garments, this will be as sustainable as rental. With the value of craftsmanship and extended lifetimes, the scheme would involve leasing durable pieces with an emotional connection to the design of the item, rather than a passing trend or cheap price. This scheme allows for changes in the size of the wearer extending the relationship over a lifetime and forming connections to the social appropriateness of the garment.

Limitations and areas for further research

Primary research in the paper was informative and provided a dualised result in both emotional attachment and emotional durability. Most interestingly are the durable items, which can be replicated for longevity and multiple user lifetimes. This method is time consuming, hence the small number of participants. It is worth considering a longer study via digital engagement with fashion brands, an intensive consumer feedback, of their most loved items. This could provide data for garment technologist and product developers over and above returns rates and reviews.

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United nations

Appendices:

1. Images of garments


Participant 1

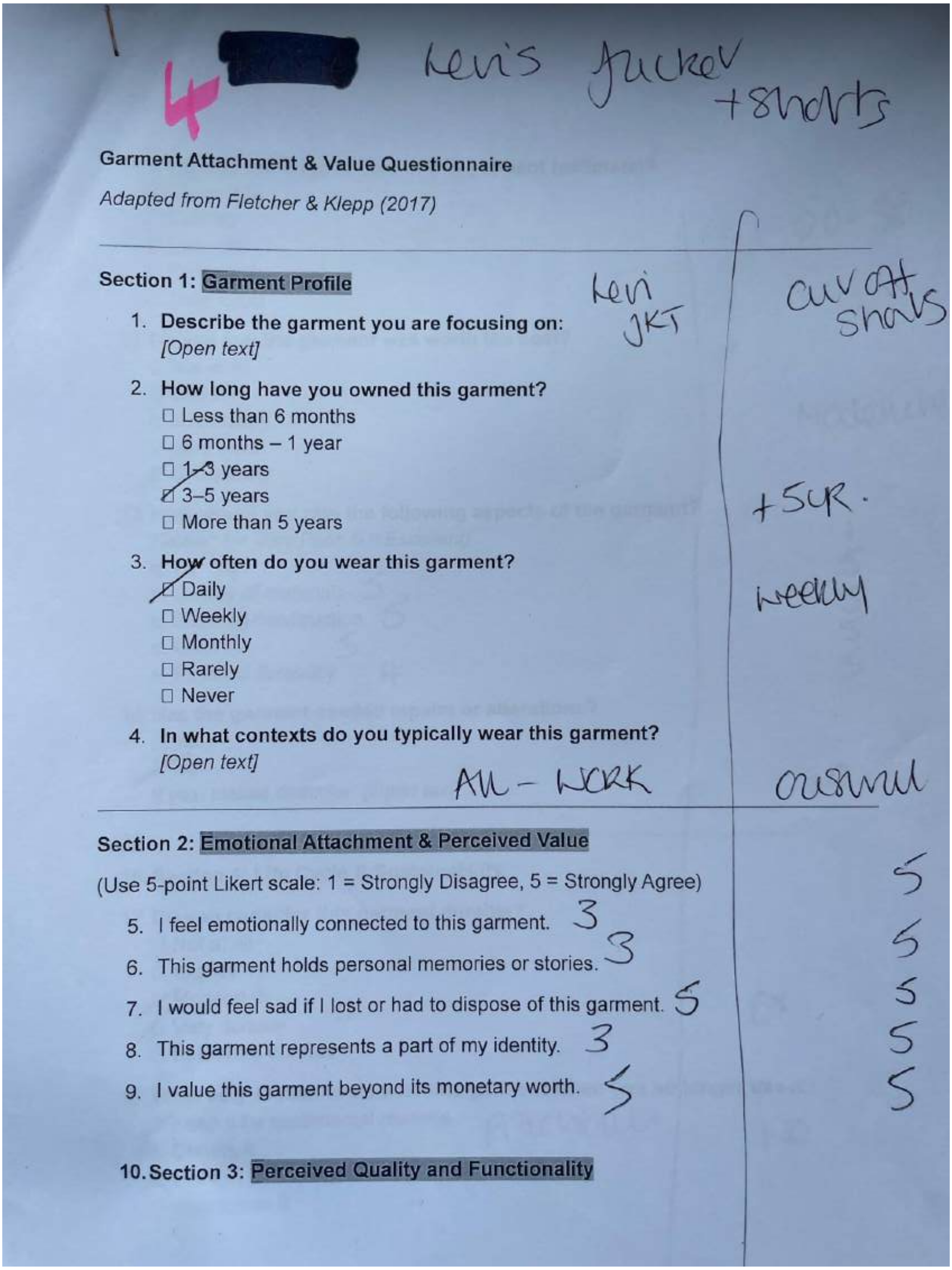

Participant 1

Participant 2

Participant 3

Participant 4

2.Transcripts and notes



4 [redacted] Levi's Jacket + shorts

Garment Attachment & Value Questionnaire

Adapted from Fletcher & Klepp (2017)

Section 1: Garment Profile

1. **Describe the garment you are focusing on:** Levi JKT | cut off shorts
   [Open text]
2. **How long have you owned this garment?**
   ☐ Less than 6 months
   ☐ 6 months – 1 year
   ☐ 1–3 years
   ☑ 3–5 years | +5YR.
   ☐ More than 5 years
3. **How often do you wear this garment?**
   ☑ Daily
   ☐ Weekly | weekly
   ☐ Monthly
   ☐ Rarely
   ☐ Never
4. **In what contexts do you typically wear this garment?**
   [Open text] All - WORK | casual

Section 2: Emotional Attachment & Perceived Value

(Use 5-point Likert scale: 1 = Strongly Disagree, 5 = Strongly Agree)

5. I feel emotionally connected to this garment. 3 | 5
6. This garment holds personal memories or stories. 3 | 5
7. I would feel sad if I lost or had to dispose of this garment. 5 | 5
8. This garment represents a part of my identity. 3 | 5
9. I value this garment beyond its monetary worth. 5 | 5

10. Section 3: **Perceived Quality and Functionality**

2. Ossie Clark. [redacted]

Garment Attachment & Value Questionnaire

Adapted from Fletcher & Klepp (2017)

Viscose crepe full length wrap skirt dress

Section 1: Garment Profile

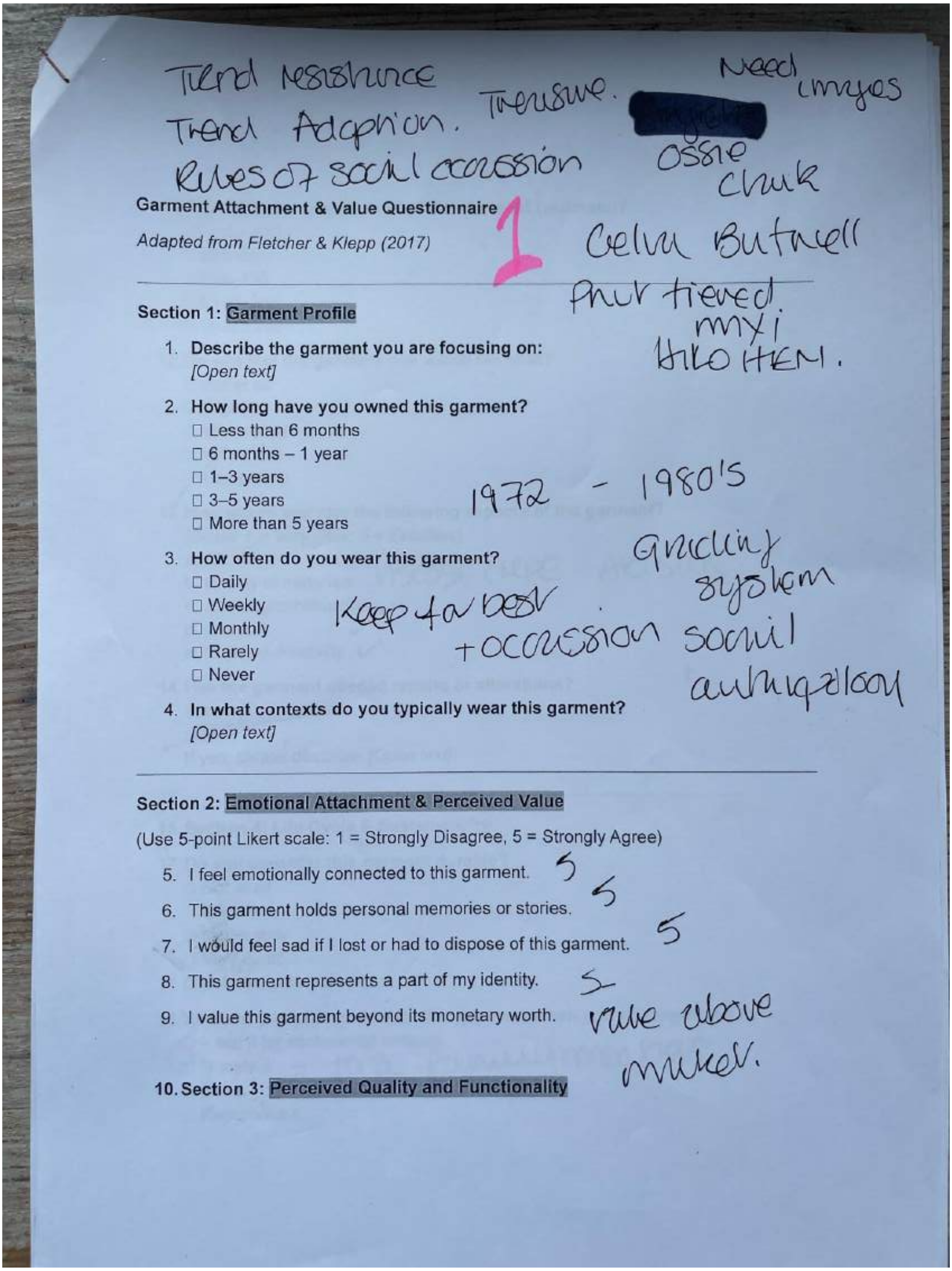
1. **Describe the garment you are focusing on:** 50 years.
   [Open text]
2. **How long have you owned this garment?**
   ☐ Less than 6 months
   ☐ 6 months – 1 year
   ☐ 1–3 years
   ☐ 3–5 years
   ☐ More than 5 years ✓
3. **How often do you wear this garment?** Regularly. Social occassion eve of dressing up.
   ☐ Daily
   ☐ Weekly
   ☐ Monthly
   ☐ Rarely
   ☒ Never
4. **In what contexts do you typically wear this garment?**
   [Open text]

Section 2: Emotional Attachment & Perceived Value

(Use 5-point Likert scale: 1 = Strongly Disagree, 5 = Strongly Agree)

5. I feel emotionally connected to this garment. 5
6. This garment holds personal memories or stories. 5
7. I would feel sad if I lost or had to dispose of this garment. - Archive
8. This garment represents a part of my identity. 5
9. I value this garment beyond its monetary worth. £2000

10. **Section 3: Perceived Quality and Functionality**



Trend resistance Need images
Trend Adoption. Treasure. [redacted]
Rules of social occasion Ossie Clark

Garment Attachment & Value Questionnaire 1

Adapted from Fletcher & Klepp (2017) Celia Birtwell

Section 1: Garment Profile Print tiered maxi Hiko Hem.

1. **Describe the garment you are focusing on:**
   [Open text]
2. **How long have you owned this garment?**
   ☐ Less than 6 months
   ☐ 6 months – 1 year
   ☐ 1–3 years
   ☐ 3–5 years 1972 - 1980's
   ☐ More than 5 years
3. **How often do you wear this garment?** Grading system
   ☐ Daily
   ☐ Weekly Keep for best.
   ☐ Monthly
   ☐ Rarely + occasion social
   ☐ Never ambiguity
4. **In what contexts do you typically wear this garment?**
   [Open text]

Section 2: Emotional Attachment & Perceived Value

(Use 5-point Likert scale: 1 = Strongly Disagree, 5 = Strongly Agree)

5. I feel emotionally connected to this garment. 5
6. This garment holds personal memories or stories. 5
7. I would feel sad if I lost or had to dispose of this garment. 5
8. This garment represents a part of my identity. 5
9. I value this garment beyond its monetary worth. value above market.

10. Section 3: Perceived Quality and Functionality

[redacted]

1

Garment Attachment & Value Questionnaire

Adapted from Fletcher & Klepp (2017)

Practical.
Comfortable
Replica of an older item
aumanfruje
CARGO Jean.
8-'pockets
WASH "gold."

Section 1: Garment Profile

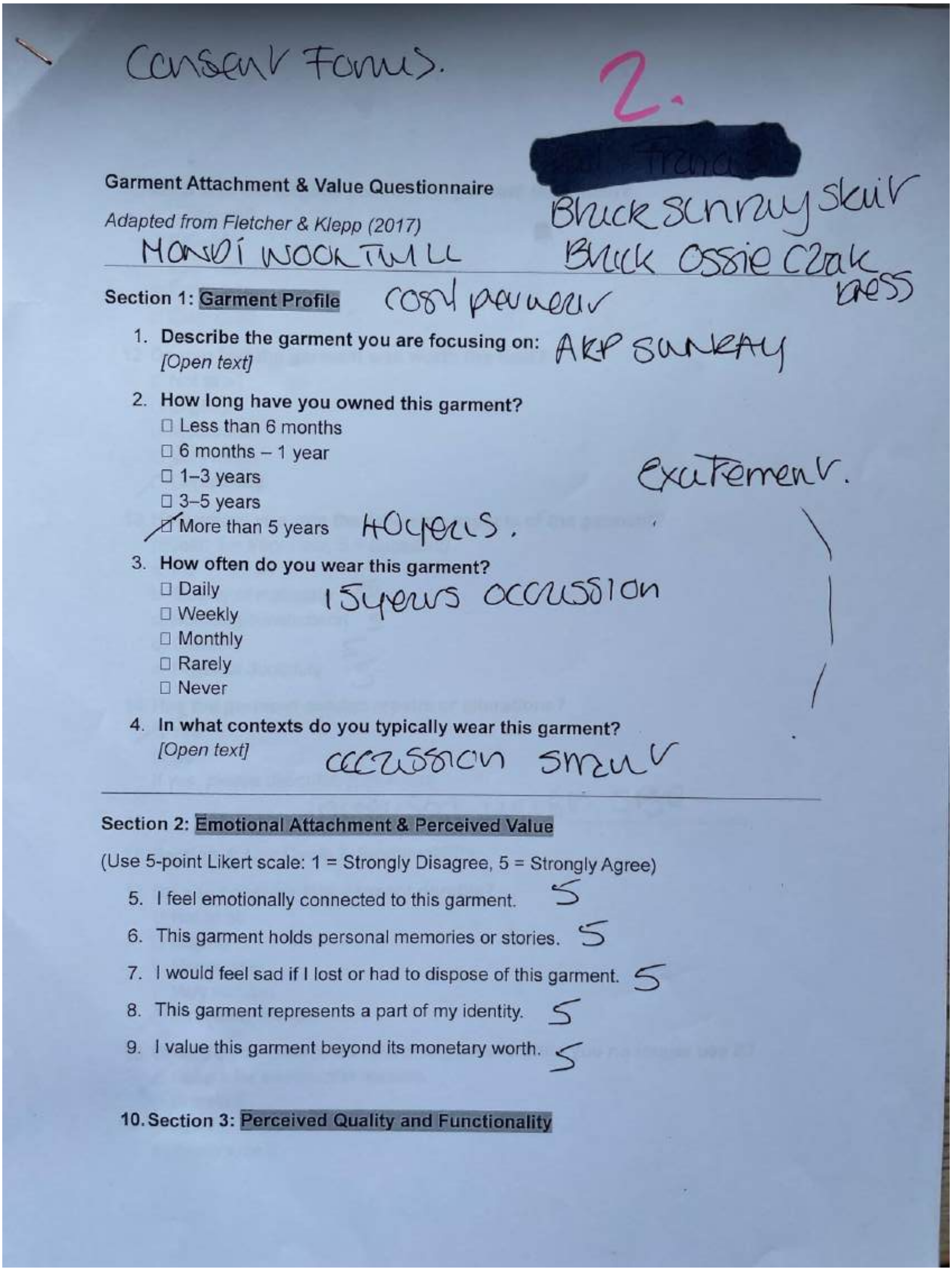
1. **Describe the garment you are focusing on:**
   [Open text]
2. **How long have you owned this garment?**
   ☐ Less than 6 months
   ☑ 6 months – 1 year
   ☐ 1–3 years
   ☐ 3–5 years
   ☐ More than 5 years
3. **How often do you wear this garment?**
   ☐ Daily
   ☑ Weekly
   ☐ Monthly
   ☐ Rarely
   ☐ Never
4. **In what contexts do you typically wear this garment?**
   [Open text] As often as possible

Section 2: Emotional Attachment & Perceived Value

(Use 5-point Likert scale: 1 = Strongly Disagree, 5 = Strongly Agree)

5. I feel emotionally connected to this garment. 5
6. This garment holds personal memories or stories. 5
7. I would feel sad if I lost or had to dispose of this garment. 5
8. This garment represents a part of my identity. 5
9. I value this garment beyond its monetary worth. 5

10. **Section 3: Perceived Quality and Functionality**



Consent Forms.

2.

[redacted]

Garment Attachment & Value Questionnaire

Adapted from Fletcher & Klepp (2017)

Black scrunchy skirt

MONDI WOOL TWILL

Black Ossie Clark dress

Section 1: Garment Profile

cosy pullover

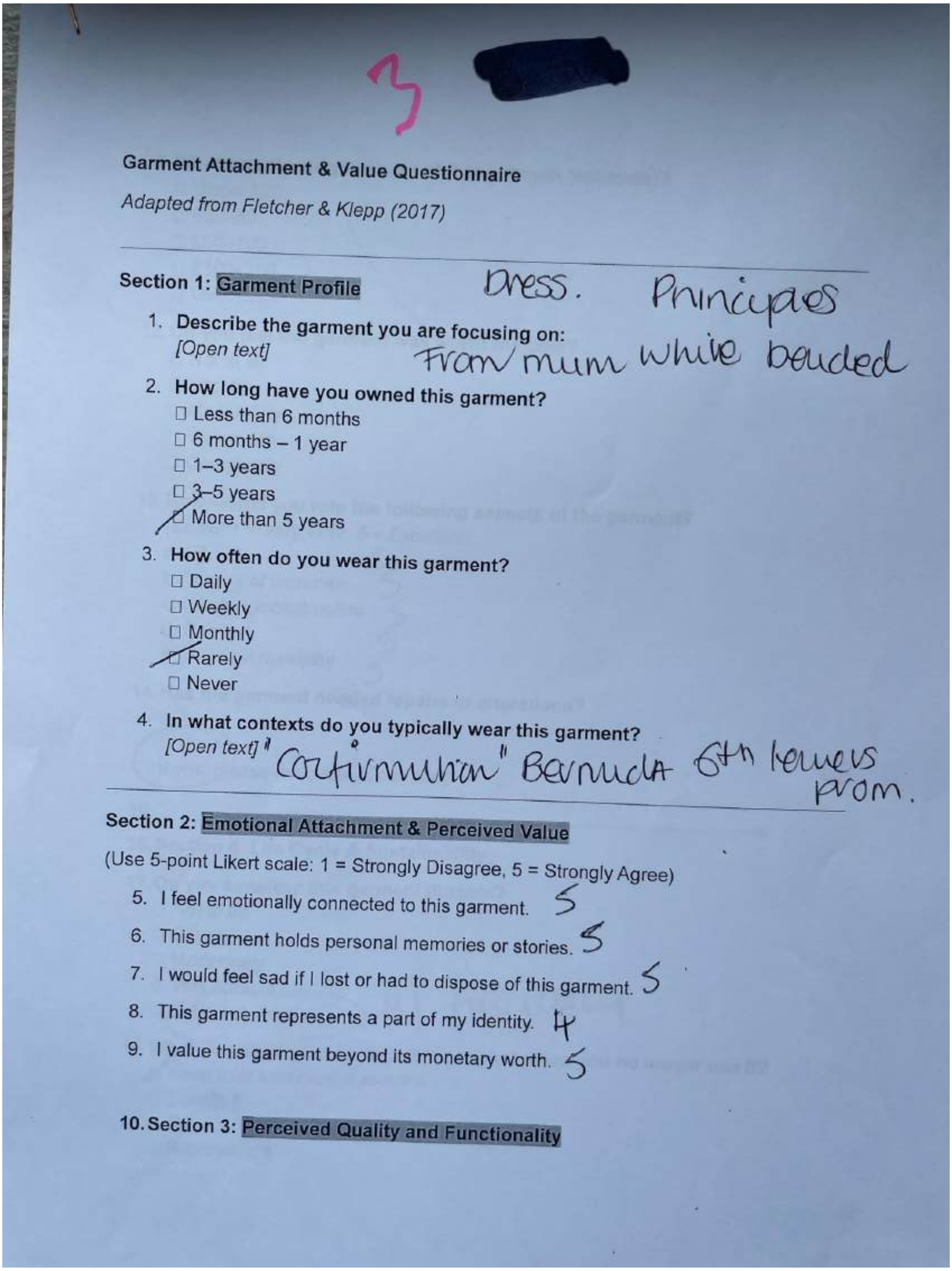
1. **Describe the garment you are focusing on:** *[Open text]* AKP SUNRAY
2. **How long have you owned this garment?**
   - ☐ Less than 6 months
   - ☐ 6 months – 1 year
   - ☐ 1–3 years
   - ☐ 3–5 years
   - ☑ More than 5 years 40 years.
3. **How often do you wear this garment?** 15 years occasion
   - ☐ Daily
   - ☐ Weekly
   - ☐ Monthly
   - ☐ Rarely
   - ☐ Never
4. **In what contexts do you typically wear this garment?** *[Open text]* occasion smart

Excitement.

Section 2: Emotional Attachment & Perceived Value

(Use 5-point Likert scale: 1 = Strongly Disagree, 5 = Strongly Agree)

5. I feel emotionally connected to this garment. 5
6. This garment holds personal memories or stories. 5
7. I would feel sad if I lost or had to dispose of this garment. 5
8. This garment represents a part of my identity. 5
9. I value this garment beyond its monetary worth. 5
10. **Section 3: Perceived Quality and Functionality**



3 [redacted]

Garment Attachment & Value Questionnaire

Adapted from Fletcher & Klepp (2017)

Section 1: Garment Profile

1. **Describe the garment you are focusing on:**
   [Open text] Dress. Principles. From mum white beaded
2. **How long have you owned this garment?**
   - ☐ Less than 6 months
   - ☐ 6 months – 1 year
   - ☐ 1–3 years
   - ☐ 3–5 years
   - ☑ More than 5 years
3. **How often do you wear this garment?**
   - ☐ Daily
   - ☐ Weekly
   - ☐ Monthly
   - ☑ Rarely
   - ☐ Never
4. **In what contexts do you typically wear this garment?**
   [Open text] "Confirmation" Bermuda 6th formers prom.

Section 2: Emotional Attachment & Perceived Value

(Use 5-point Likert scale: 1 = Strongly Disagree, 5 = Strongly Agree)

5. I feel emotionally connected to this garment. 5
6. This garment holds personal memories or stories. 5
7. I would feel sad if I lost or had to dispose of this garment. 5
8. This garment represents a part of my identity. 4
9. I value this garment beyond its monetary worth. 5

10. **Section 3: Perceived Quality and Functionality**

3 [redacted]

High frequency

Garment Attachment & Value Questionnaire

Adapted from Fletcher & Klepp (2017)

Section 1: Garment Profile M+S Linen

1. **Describe the garment you are focusing on:**
   [Open text] Stripe shirt 10 years. Primark
2. **How long have you owned this garment?**
   ☐ Less than 6 months
   ☐ 6 months – 1 year
   ☐ 1–3 years
   ☐ 3–5 years
   ☐ More than 5 years ✓
3. **How often do you wear this garment?**
   ☐ Daily
   ☑ Weekly
   ☐ Monthly
   ☐ Rarely
   ☐ Never
4. **In what contexts do you typically wear this garment?**
   [Open text] casual relax

Section 2: Emotional Attachment & Perceived Value

(Use 5-point Likert scale: 1 = Strongly Disagree, 5 = Strongly Agree)

5. I feel emotionally connected to this garment. 5
6. This garment holds personal memories or stories. - Develop F. sense 3
7. I would feel sad if I lost or had to dispose of this garment. 3
8. This garment represents a part of my identity. 5
9. I value this garment beyond its monetary worth. 5
10. **Section 3: Perceived Quality and Functionality**

3. Consent Forms

CONSENT FORM

Participant name: 1

Company and role covered: Wardrobe audit participant

Email and/or phone number:

Researcher: Nicola Mansfield

Position: Senior Lecturer

Contact details:

Topic/Title of Research Project: Design for Degrowth

This consent form, a copy of which will be left with you for your records and references, is only part of the process of the informed consent. It should give you an idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, of information not included here, please do not hesitate to ask.

1. Use of material. I will use the material from this study to write a research thesis to be submitted for assessment of a Degree

2. There may be no direct benefits to you as a study participant. You will not be paid and the costs are in the form of your time for participating in the study.

3. Complete anonymity will be maintained. Your real name will not be used at any point in the written thesis or in any subsequent publications. You will be given a pseudonym that will be used in all verbal and written records and reports. Your education institution and professional practice setting will also be anonymised.

4. An audio-recorder will be used during the interview – but no video-recorder – for the researcher to review the information provided by the subject. In no way will this content be duplicated. At your discretion, these recordings will either be destroyed or returned to you. You have the right to request that the audio-recorder is turned off at any point.

5. Your participation in this research is voluntary. You have the right to withdraw at any point of the study, for any reason and without any prejudice. The information collected, records and the written reports will be turned over to you at your request. You may of course refuse to answer any of the questions posed.

The signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researcher, sponsor or involved institutions for their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence.

Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

Having read this informed consent form,

Please tick within the bracket [✓]

1. I confirm that I have read and understood the information sheet for the above study and have had the opportunity to ask questions about the interview procedure.

[✓]

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving reason to the named researcher.

[✓]

3. I agree to take part in the above research project.

[✓]

4. I agree to the interview being audio-recorded (not-applicable in the case of email interviews)

[ ]

5a. I understand that my real name will not be used in the research

[✓]

OR

5b. I agree to proceed with the interview only if my real name is used in the

[ ]

Angela Smith	22/6/25	A Smith
Name of Participant	Date	Signature
Nicola Mansfield.	22/6/25	NEM
Name of Researcher	Date	Signature

Eco-Design as a Catalyst for Circular Innovation: A Knowledge-Based Framework to Sustainable Product Development

Enrica Monticelli

Executive PhD Student

Department of Design

Politecnico di Milano

Italy

Francesco Zurlo

Professor of Industrial Design

Department of Design

Politecnico di Milano

Italy

Abstract

Small Domestic Appliances face increasing scrutiny for their environmental impact, driven by short lifespans, low recyclability and high resource consumption. This study explores the application of a company-specific Ecodesign tool to support the transition toward circular product innovation. The Handbook of Guidelines to Design Low-Environmental Impact Products provides a structured framework encompassing 7 Eco-design strategies, 27 sub-strategies, and 157 detailed checklists. These guidelines address sustainability across all phases of a product's life cycle: from material sourcing to end-of-life recovery. Ten pilot projects applied the tool during early development stages, engaging cross-functional teams in structured workshops. The systematic use of checklists enabled the identification of specific circular design improvements while highlighting knowledge gaps across the product organization. The results highlight the Ecodesign tool's effectiveness in embedding design for sustainability principles in all types of company appliances.

Keywords: Ecodesign, Circular Product Innovation, Small Domestic Appliances, Organizational sustainability transition

Introduction

Small Domestic Appliances (SDA) are widespread in modern households, playing a vital role in enhancing everyday comfort and convenience. However, their environmental footprint has become a growing concern. Characterized by short lifespans, complex material compositions and limited recyclability, small equipment, including SDA, contributed over 17.4 million metric tons to global e-waste in 2019, making it the largest category by volume (Waste from Electrical and Electronic Equipment (WEEE) - European Commission; Forti et al., 2020). This waste is often not properly collected or treated, resulting in the loss of valuable resources and the emission of hazardous substances. Beyond end-of-life issues, the production and use of SDAs are also resource and energy-intensive (Alejandre et al., 2022).

In response to these challenges, the transition from linear to a circular economy has emerged as a strategic imperative for manufacturers (Dennison et al., 2024). This shift is reinforced by regulatory frameworks such as the European Commission's Circular Economy Action Plan and the new Ecodesign for Sustainable Products Regulation (ESPR), which entered into force in July 2024 (EU Commission 2020, 2024) and are aimed at promoting sustainability by extending product lifecycles and reducing environmental impacts through design. They push companies to rethink how they design, develop, and deliver their products.

Despite the growing emphasis on Ecodesign, a persistent gap remains in operationalising circularity within sector-specific contexts (Bocken *et al.*, 2016; Fabrizio Ceschin and Gaziulusoy, 2016; Mendoza *et al.*, 2017; Vezzoli *et al.*, 2021). Many existing tools lack the specificity needed to be effective in fast-paced, cost-sensitive industrial environments and companies often face difficulties in embedding circular strategies into early-stage design activities (Takacs, Brunner and Frankenberger, 2022; Rotondo *et al.*, 2025). This paper addresses this gap by presenting a case study of a major SDA manufacturer that developed and tested a customised Ecodesign handbook, co-created with academic partners. The study investigates how structured tools and collaborative workshops can support the integration of circular principles into practice.

The research is guided by the following questions:

1. RQ1: How can a company-specific Ecodesign tool support the integration of circular design strategies into the early stages of product development?
2. RQ2: What types of circular innovation concepts emerge when cross-functional teams apply Ecodesign checklists in real-world design settings?
3. RQ3: What knowledge gaps are revealed through the practical application of structured Ecodesign tools?

By addressing these questions, the study contributes to the growing field of design for circularity and offers insights into how Ecodesign tools can move beyond theoretical guidance to support applied circular innovation and knowledge creation.

Theoretical framework

At the regulatory level, the European Union has progressively integrated Ecodesign requirements into broader circular economy policy. The Ecodesign Directive (Directive 2009/125/EC) was a first step in mandating environmental performance standards for energy-related products (*Directive - 2009/125 - EN - EUR-Lex*, no date). More recently, the Ecodesign for Sustainable Products Regulation (ESPR) extends binding design criteria, such as reparability, recyclability, durability and material efficiency to a wide range of product groups, positioning Ecodesign as a regulatory cornerstone of the EU's green transition (EU Commission, 2024). This is supported by the Circular Economy Action Plan (EU Commission, 2020), and emerging tools like the Digital Product Passport, which aim to close material loops and increase design transparency. However, despite the presence of a robust policy framework, implementation within industry remains inconsistent, particularly among firms managing multi-product portfolios, due to the absence of direct product-specific requirements and the limited applicability of generic Ecodesign tools to complex, varied product ranges (Dekoninck et al., 2016; Fondazione Symbola e Deloitte Private e Poli:Design, 2024b; Rossi et al., 2019).

In academic discourse, Ecodesign theory has evolved significantly from early Life Cycle Design paradigms, which advocated for environmental considerations across the entire product lifecycle (Vezzoli and Manzini, 2008; Tischner *et al.*, 2010), toward more integrated models aligned with circular innovation strategies (Bocken et al., 2016; Pieroni, McAloone and Pigosso, 2021b).

Circular innovation is defined as the systemic reconfiguration of products, services, and value networks to retain materials, energy, and functionality within closed, regenerative loops (Pieroni, McAloone and Pigosso, 2021a), thereby enabling the decoupling of economic growth from resource use. This entails maintaining product value through strategies such as reuse, refurbishment, remanufacturing, and recycling (Ellen MacArthur Foundation, 2024). As such, Ecodesign plays a critical role in enabling circular innovation by guiding the product development community through specific tools like checklists and guidelines, instrumental in translating high-level ambitions into actionable design requirements (Pigosso et al., 2013; Rossi, et al., 2016, 2016; Suppipat and Hu, 2022). When effectively applied, these tools foster cross-functional dialogue, strengthen sustainability-oriented routines, and help surface hidden trade-offs between performance, cost, and environmental impact (F Ceschin and Gaziulusoy, 2016; Wrigley, 2017). However, despite the strategic potential of Ecodesign in supporting circular transitions, implementation remains a challenge. Studies consistently highlight a persistent gap between systemic eco ambitions and practical tool usage, exacerbated by fragmented environmental knowledge within design teams and limited collaboration across functions (Idil Gaziulusoy, 2015; Dekoninck et al., 2016; Lüdeke-Freund et al., 2019).

To address the implementation barriers, recent research calls for context-specific Ecodesign tools that are more aligned with the realities of industrial practice. Rather than relying on generic frameworks, tailored approaches are better suited to support knowledge acquisition and integration within established routines (Mendoza *et al.*, 2017; Bögel *et al.*, 2019). These customised tools are particularly important in complex organisations with multi-brand portfolios and distributed product development teams, where internal learning and coordination are essential for circular innovation to scale (Rossi et al., 2016). The present study contributes to this growing body of research by examining the application of a company-specific toolkit across ten SDA pilot projects, examining its contribution in supporting the circular innovation agenda and cross- functional learning.

Methodology

This study adopts an Insider Action Research approach (Coghlan, 2007), leveraging the dual role of the researcher as both practitioner and investigator within a major SDA manufacturer. By developing and implementing a company-specific Ecodesign framework, the research treats the tool as a learning artefact embedded in design routines. This perspective enables participatory observations that allow for an in-depth exploration of the barriers, enablers, and knowledge required to embed circularity into early-stage product development (Muratovski, 2016)

The following sections detail the methodological trajectory of the study: the structure of the Ecodesign tool (Section 4.1), its implementation across pilot workshops (Section 4.2) and the protocols adopted for data collection and interpretation (Sections 4.3).

Company-Specific Ecodesign Tool

The Ecodesign tool was co-developed by company experts and the LeNSlab research group at Politecnico di Milano through a structured, multi-phase process. It features a hierarchical structure of strategies, sub-strategies and guidelines, each linked to checklist items. Adapted from general Ecodesign frameworks, these elements were tailored to the company's product typologies, material flows, and environmental priorities through desk research, product family mapping and environmental profile analysis (Monticelli and Vezzoli, 2025). A summary is provided in Table 1.

Level	Description	Quantity
Strategies	High-level Ecodesign goals adapted to SDA	7
Sub-strategies	Operational directions aligned with life cycle priorities	27
Guidelines	Product-relevant rules and heuristics	154
Checklists	Evaluation questions for internal product reviews	154

Table 1: Company-specific Ecodesign tool (Monticelli and Vezzoli, 2025)

Each checklist is designed to support qualitative assessment of guideline implementation using a 3-point scale (fully applied, partially applied, not applied), enabling the identification of both feasible opportunities and perceived barriers to the implementation of each guideline while enabling structured reflection and early-stage integration of sustainability objectives in the product development process (Luttropp and Lagerstedt, 2006).

Pilot Project Implementation and Workshop Structure

The pilot workshops served as both the primary research setting and a key methodological instrument for piloting the Ecodesign checklists within early-stage product development processes. Adopting a co-design methodology (Sanders and Stappers, 2008) each session was structured as a situated design intervention, where cross-functional teams collaboratively explored sustainability-oriented improvements. The workshops followed a three-step sequence designed to activate both analytical and generative dimensions of Ecodesign: (1) *Baseline Assessment*, applying the checklist to a prior-generation product to establish a reference point; (2) *New Product Assessment*, evaluating emerging concepts against the same criteria to identify sustainability gaps and advances; and (3) *Opportunity Framing*, facilitating the contextual ideation of circular interventions. The application of the checklists supported the identification of circular innovation opportunities and product-specific constraints, consistent with evaluative practices in early-stage sustainable design (Bocken et al., 2016). Beyond technical assessment, the workshops functioned as arenas for organisational learning. Drawing on Argyris and Schön's distinction (Argyris and Schön, 1997), the structured co-design process enabled both single-loop learning, focused on technical optimisation and double-loop learning, where teams critically reflected on underlying assumptions shaping product development routines. Data generated during the sessions, including design concepts, team reflections, direct observations, and checklist responses, were documented in real time and later coded for analysis. This dual role of the workshops, as both evaluation tools and learning platforms, aligns with established practices in participatory design research and has been shown to enhance the adoption of sustainability practices within firms (Rodrigues, Pigosso and McAloone, 2017). Projects were purposively selected to reflect a variety of technical complexities, functional requirements, and environmental hotspots across the product life cycle, in accordance with sampling approaches typical of design research (Blessing and Chakrabarti, 2009). This format positioned the workshop as both a design intervention and a knowledge-sharing platform, enabling collective interpretation and in-situ refinement of the tool (Bjögvinsson, Ehn and Hillgren, 2012; Brandt, Binder and Sanders, 2012). Table 2 summarises the overall scope and organisational reach of the pilot programme:

Metric	Value
Total Pilot Projects	10
Countries Involved	Italy, Germany, UK
Product Categories	Ironing, Comfort, Coffee Machines, Food Preparation
Total Participants	100+
Functions Represented	R&D, Design, Quality, Marketing, After Sales, Program Management

Table 2: Overview of Ecodesign pilot project implementation and workshop sampling.

Data Analysis

The data analysis combined deductive structuring with inductive coding. Checklist responses marked as "yes" or "partially" were considered feasible circular innovation concepts, while "no" responses indicated perceived barriers. Only actions directly aligned with circular economy objectives were retained, based on a typology that distinguishes between slowing, extending, and closing resource loops (Bocken *et al.*, 2016). Actions focused solely on efficiency improvements or compliance without circular intent were excluded. Concepts were then grouped into three clusters:

(1) *Slowing loops* – strategies aimed at extending product lifespan and maintaining functionality (e.g. durability, reparability);
(2) *Extending loops* – design features enabling adaptation, modularity, or upgradeability;
(3) *Closing loops* – measures supporting reuse, material separation, and recyclability.

This framework enabled cross-case analysis of how circular design strategies were activated or constrained across pilot projects. In parallel, a coding scheme was developed to capture the knowledge gaps that limited the implementation of these same strategies. These gaps were identified through workshop observations, annotated checklists, and facilitator notes, and analysed using an inductive coding approach. The analysis concentrated on domain-specific knowledge needed to operationalise circularity in practice. Each gap was first linked to a specific Ecodesign sub-strategy and then grouped under the corresponding strategic loop: *slowing, extending* or *closing.* Examples included insufficient knowledge of reversible joining methods for repairability (slowing), limited experience with modular architectures for upgradeability (extending), or gaps in material traceability relevant to recyclability (closing).

Results

The analysis of checklist responses, workshop discussions, and facilitator notes based on ethnographic observations enabled the identification of the most recurrent circular innovation concepts, as well as the barriers and knowledge gaps that limited their implementation. Findings were first organized by Ecodesign sub-strategy, then grouped under the three overarching circular design loops: slowing, extending, and closing resource flows. The results are presented in two parts:

- distribution of feasible circular innovation concepts and associated barriers
- identification of knowledge gaps affecting circular design strategies.

Circular Innovation Concepts and Barriers

Table 3 synthesizes the insights generated across ten pilot workshops by mapping the most recurrent feasible circular innovation concepts and the corresponding implementation barriers identified through the application of Ecodesign checklists. This classification enables a structured interpretation of how circular principles are being activated, or constrained, within early-stage product development.

The table distinguishes between feasible concepts (identified through "yes" and "partially" responses) and barriers (indicated by "no" responses). By combining this scoring with qualitative insights from the workshops, the analysis enables a comparative understanding of which circular strategies are already embedded in design practice and which require further development. This synthesis serves as a diagnostic tool to guide future Ecodesign integration and inform strategic decisions for scaling circular innovation.

Cluster	Sub-strategy	Feasible Concepts	Barriers	Key outcomes emerging
Slowing loops	2.1 Extend the lifespan of components	20	0	Already considered best practice
	2.3 Facilitate maintenance	61	5	Maintenance is well understood and integrated
	2.4 Facilitate repairing	38	17	Barriers include joining techniques and wiring complexity
	2.6 Design for reliability	26	4	Reliability pursued, but not always linked to circular objectives
	4.2 Reversible fastenings	105	67	Applied in some platforms, but inconsistently across subsystems
Extending loops	2.2 Facilitate upgrading and adaptability	34	18	Upgradeability logic limited; modularity remains partial
	5.4 Flexible material consumption during use	20	10	Flexibility relevant only for selected product types
Closing loops	2.5 Facilitate reuse and remanufacturing	42	27	Components reuse not structurally integrated
	3.1 Select materials with efficient recycling tech	38	12	Cost-performance trade-offs influence selection
	3.2 Facilitate end-of-life collection	11	9	End of Life logistics rarely addressed in design
	3.3 Material identification	47	12	Material marking becoming common practice
	3.4 Minimise incompatible materials	31	23	Often overlooked; not systematically addressed
	3.5 Facilitate cleaning	78	23	Not a design driver, but some best practices in place
	4.1 Facilitate disassembly and separation	47	33	Disassembly efforts vary across teams
	4.3 Facilitate automated	31	33	Rarely supported by current

Cluster	Sub-strategy	Feasible Concepts	Barriers	Key outcomes emerging
	disassembly			configurations
	4.4 Design for crushing separation	3	36	Poorly understood and rarely applied
	6.1 Use renewable materials	19	20	Seldom prioritised due to sourcing and durability concerns
	6.2 Use recycled materials	18	9	Growing adoption, especially for plastics and metals

Table 3: Recurrent circular innovation concepts and barriers across ten pilot projects.

Within the *slowing loops* cluster, strategies such as extending component lifespan (2.1) and facilitating maintenance (2.3) were frequently activated, with high feasibility and minimal resistance. These reflect mature practices already embedded in existing development processes. Conversely, while reversible fastenings (4.2) showed high feasibility scores, they also revealed significant barriers, primarily due to inconsistent application across subsystems and lack of standardization. The sub-strategy for repair (2.4) likewise exposed technical constraints linked to joining methods and wiring, despite its conceptual alignment with circularity goals.

In the *extending loops* domain, efforts to facilitate upgrading and adaptability (2.2) emerged with moderate feasibility but notable barriers. These include limited implementation of modular logic and insufficient consideration for cross-generational compatibility. This suggests that although the intent to support adaptability exists, enabling conditions are not yet structurally embedded.

The *closing loops* cluster revealed more uneven implementation. While the facilitation of reuse and remanufacturing (2.5), material identification (3.3), and cleaning for recycling (3.5) showed some integration, they remain hindered by systemic challenges. Reverse logistics and end-of-life design considerations are rarely integrated into development workflows. Sub-strategies such as design for crushing separation (4.4) and automated disassembly (4.3) scored poorly both in feasibility and in understanding, indicating low maturity within current organizational routines.

What emerges, therefore, is not just a gap in implementation but a divergence in epistemic readiness: while some strategies are supported by established knowledge regimes and incremental technical interventions, others remain aspirational, lacking the procedural framework needed for effective translation into practice. As such, Table 3 should not be read merely as a diagnostic assessment, but as a directional map that highlights where design capabilities are currently anchored, and where they must evolve to enable a more systemic uptake of circular innovation.

Overall, Table 3 illustrates that slowing strategies are the most established, while closing loops remain the most constrained. The mapping of scores and qualitative insights enables the identification of priority areas for targeted knowledge development, cross-functional alignment, and process reconfiguration to support circular innovation in product development.

Knowledge gaps affecting circular design strategies

Insights were derived through the triangulation of ethnographic observations and facilitated discussions during workshops and annotated checklists. Saturation effects were observed across the ten workshops, with consistent knowledge gaps emerging regardless of product category or team composition (Table 4).

Circular Design Cluster	Knowledge Gaps (K)	Knowledge Enablers (E)
Slowing loops	K.1 Consumers' sustainable behavioural patterns	E.1 Design for Sustainable Behaviours E.2 Consumers' user patterns
Extending loops	K.2 Design-for-repair culture K.3 No on-site repair logic K.4 Design rules for adaptability and upgrades	E.3 Repairability guidelines E.4 Modular design logic based on functional decomposition E.5 Upgradeability and adaptability criteria
Closing loops	K.5 Design for recycling (material compatibility) K.6 Design for disassembly (crushing separation and automated) K.7 Design for recycling (monomaterial logic) K.8 Design for disassembly (confused with design for assembly) K.9 Bio-based materials application K.10 Knowledge on facilitating reuse and remanufacturing K.11 Knowledge on end-of-life collection and transportation	E.6 Material selection tools for recyclability E.7 Case studies on mono-material product design E.8 Design-for-disassembly heuristics E.9 Recyclability standards E.10 Bio-based materials E.11 Remanufacturing design strategies and reverse logistics guidelines E.12 End of Life logistics integration in design and service planning

Table 4: Circular Innovation knowledge gaps and enablers

Discussion

The implementation of Ecodesign guidelines in the analysed case study provides significant insights into how circular innovation can be practically advanced within a manufacturing context. A key contribution of this study is its ability to move beyond the abstraction of circular economy ambitions and activate them through micro-level design actions. The deployment of a checklist system articulated across seven Ecodesign strategies enabled design teams to systematically explore product-specific pathways toward circularity. The tool was not simply evaluative, but generative: it triggered cicular innovation concepts through cross-functional trade-offs.

From an organisational learning perspective, the workshops played a pivotal role in fostering shared understanding of Ecodesign principles across teams traditionally siloed by function or performance metrics. Here, circular innovation was not imposed as a top-down goal but co-developed through situated negotiation and application of shared heuristics, within the Ecodesign workshop dynamic. This approach aligns with recent scholarship that identifies co-design, participatory reflection, and interdisciplinary exchange as essential mechanisms for embedding circularity in innovation practices (Cluzel et al., 2015; Rejeb et al., 2022). The checklists mediated between abstract Ecodesign ambitions and operational constraints. It enabled teams to engage in double-loop learning (Argyris and Schön, 1997), questioning existing assumptions about product value, resource optimisation and end-of-life scenarios. This study offers a relevant contribution to circular innovation by operationalising Ecodesign strategies across a diverse product portfolio, yet several limitations must be acknowledged. First, the findings are context-specific, emerging from a single firm (SDA) with a consolidated design-oriented culture, limiting generalisability. Second, while the checklist tool fostered design reflections, the absence of integrated Life Cycle Assessment or circularity metrics constrains the ability to quantify environmental gains (Pigosso *et al.*, 2015; Rossi, Germani and Zamagni, 2016). Third, some workshops revealed a performative tendency to inflate scores or avoid negative evaluations, suggesting potential bias in self-assessment. Lastly, the study concentrated on early-stage design activities, without extending the analysis to downstream phases such as production, distribution, or product use and end-of-life. As a result, it does not capture the longitudinal effects or full life cycle impacts of the circular strategies explored, limiting insights into their systemic integration and long-term performance. Future research should adopt a broader temporal and organisational scope to evaluate how early design decisions propagate through later stages of the product lifecycle.

Conclusions

This study has demonstrated the potential of a company-specific Ecodesign handbook to facilitate the integration of circular innovation principles into the early stages of product development. By translating abstract sustainability objectives into actionable checklists, the tool supported concept-level interventions and fostered a cross-functional understanding of life cycle design paradigm. The ten pilot projects confirmed the tool's generative value across the three core circular design clusters: slowing, extending, and closing resource loops. Strategies related to slowing loops, such as product longevity and maintenance, were the most readily activated since they leveraged existing knowledge and aligned with current design routines. Extending loops, including modularity and upgradeability, showed emerging potential. However, their implementation was often constrained by the absence of shared criteria and limited integration within product strategies. More substantial challenges were identified in the implementation of closing loops. Efforts to enable disassembly, material separation, and recyclability were frequently hindered by fragmented knowledge, insufficient clarity around end-of-life recovery processes and a lack of operational guidance on secondary material use. This cross-cluster synthesis highlights the need to advance both technical enablers and organizational capabilities.

Future work should further explore how Ecodesign tools can activate long-term organizational learning, foster cross-departmental collaboration and support the emergence of a circular design culture. From a design research perspective, the study contributes to the Ecodesign and circular innovation literature by offering empirical evidence of how structured tools can operationalize sustainability strategies in practice. It emphasizes the importance of situated experimentation, cross-functional dialogue and iterative refinement in enabling the transition from intention to implementation. This work supports, therefore, the broader agenda of integrating design-led approaches into the systemic transformation toward a circular economy.

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Post-manufacturing Production – a Key Circular Economy Concept Prolonged Product Lifetime

Tatiana Nevzorova

Senior Researcher

RISE Research Institutes of Sweden

Sweden

Raul Carlsson

Senior Researcher

RISE Research Institutes of Sweden

Sweden

Abstract

Our research introduces a generic life cycle assessment-based model developed to assess economic and sustainability performance for different circular business models, emphasizing post-manufacturing production. The model is designed as a simulation tool for development of business models for a prolonged lifetime, as well as a tool to assess consumers' responses to information and incentive campaigns. This model considers customers' and other actors' needs to get information at different points throughout a prolonged product life cycle. Such information sharing is necessary to facilitate or even make it possible for consumers to be aware of, stay informed about, or even to be incentivized to participate to prolong the product's lifetime. Thus, the model includes both business to consumer communication and behavioral change as variables. Therefore, the model includes the effectiveness of various types of information channels at different moments throughout the post-manufacturing prolonged lifetime, such as at the moment of purchase and during different stages of use, refurbishing, remanufacturing, dismantling, and recycling. The specific focus of the model is to establish principles for effective indicators and data quality aspects in the relationship between post-manufacturing and its economic and sustainability production efficiency.

Introduction

The linear economy of physical products is built up as a chain of linear industrial unit processes, where final product manufacturing crowns the top of the value chain at which the point of sales establishes the main return of investments and defines the profit for the value chain. After the point of sale, the use phase and its after-market of maintenance, service, and spare parts are support systems along the linear value chain towards the end of life. Applying a circular economy perspective suggests a shift from the supply chain operations to the effective, efficient, and commercial emphasis on the *post-manufacturing production* processes aimed to increase and prolong the value creation of the product. This is key to transforming the linear economy into a circular economy that truly attracts businesses, financiers, and consumers to make the shift. Moreover, there is a strong need for companies to get some help with designing the business model and the prolonged lifetime of the product while minimizing negative sustainability impacts and maintaining sufficient economic benefits both for customers and producers (Geissdoerfer et al., 2017; Kirchherr et al., 2017).

Historically, all tools homes, clothes, knives, hammers, fishing gear, plows have been made by hand. Today, we are again at a moment where continued value creation must be deliberately shaped by our skills and intentions. The tools for sustainable survival must now be developed with similar craftsmanship: by hand, by design, and by necessity. What we do here is part of that effort.

The term *manufacture* itself traces back to the Latin *manū factus*, meaning "made by hand" (Harper, n.d.). This etymology reminds us that the production of value has always been intentional and human-driven. In the same spirit, the post-manufacturing phase should not be seen as passive or secondary, but as a space for active, skilled, and innovative value creation.

This paper introduces a new conceptual and practical framework: *Post-Manufacturing Production (PMP)*. It builds upon the observation that while reuse, repair, remanufacturing, and recycling already exist in various forms, they remain loosely coordinated and insufficiently integrated into the core industrial system. The PMP paradigm proposes a structured, operator-led, yet distributed system where each manufactured product is accompanied by voluntarily accepted or designated functional responsibilities for every relevant circularity aspect.

In a fully implemented PMP system, these roles are distributed across a network of actors remanufacturers, repairers, recyclers, service providers who ensure that products and their components achieve a near-theoretical lifetime. The PMP approach thus reframes product use and post-use as active phases of production, rather than as inevitable declines toward disposal.

To visualize and analyze such systems, we have developed a modular simulation tool that models the dynamics, costs, and benefits of circular business strategies in real-world industrial contexts. A key principle of this tool is transparency: its system architecture, logic loops, and terminology are designed to align with user intuition and harmonized standards, making results both credible and understandable.

Importantly, the PMP concept has not yet been precisely defined in the literature or in standards. By grounding it in internationally recognized frameworks—particularly the ISO 14000 and 59000 series we aim to formalize the concept and give it theoretical and methodological rigor. Standards such as ISO 14040/14044 (life cycle assessment (LCA)), ISO/TS 14076 (techno-economic evaluation), ISO 14033 (quantitative environmental information), and ISO 59020 (circularity performance indicators) provide the backbone for the model's structure.

The resulting framework supports both researchers and practitioners in quantifying and comparing circular economy strategies including retaining product lifetime, reuse, refurbishment, remanufacturing and material recovery using integrated environmental and economic simulation. It is intended to provide the tools necessary to understand and optimize the dynamics of post-manufacturing systems.

Despite increasing policy and market interest in circular economy strategies, there remains a lack of standardized, transparent tools capable of systemically comparing linear and circular value chains. Existing LCA tools often fall short when applied to dynamic, post-use processes (Saidani et al., 2019). Our framework responds to this gap by building on emerging circularity standards and modeling methodologies, offering a practical and theoretically grounded pathway toward scalable circular production systems.

Foundation in standards

Standards included in the PMP system model

To establish a well-specified circular post-manufacturing production system that involves all relevant stakeholders within the value network, we base our framework on a selection of internationally recognized standards. These standards offer a comprehensive foundation for defining the scope of responsibilities (with the help of life cycle assessment standards such as ISO 14040, ISO 14044 and ISO/TS 14048 as well as circular economy system model standards such as ISO 59004, ISO 59010 and ISO 59020), ensuring accurate data acquisition (ISO 14033), enabling performance calculations (ISO 14045, ISO 14076 and ISO 59020), relations between value output and invested input (ISO 14045), as well as how to acquire (ISO 14033) and share data across value networks (ISO/TS 14048 and ISO 59014). Their integration supports our ambition to design a robust, data-driven circular economy model focused on post-manufacturing processes.

The simulation tool explicitly integrates methodological requirements and guidance from the several groups of standards. For structuring the overall *value system*, we incorporate ISO 59004, which provides a circular economy framework, principles and key definitions. This is complemented by ISO 14040 and ISO 14044, which establish foundational principles, framework and requirements for LCA. Interoperability and data consistency are critical for any circular model. To address this, we use ISO/TS 14048 for standardized LCA data documentation, ensuring that environmental data can be reliably shared and reused across systems. These standards help us model system boundaries and clarify roles across the product lifecycle, a crucial element in managing post-manufacturing value.

System performance measurement is another essential dimension of the circular PMP system. ISO 14045 offers a framework for assessing the eco-efficiency of product systems by analyzing the relationship between environmental impacts and value creation. ISO/TS 14076 adds to this by introducing methods for evaluating the performance of complex techno-economic systems, allowing us to simulate system behavior in dynamic conditions. Moreover, ISO 59020 introduces specific indicators to measure circularity performance, making it possible to benchmark progress and identify improvement areas.

For *metrology and measurement*, ISO 14033 plays a central role. It provides guidelines for collecting quantitative environmental information, which supports both decision-making and system control. This standard ensures that environmental metrics are robust, reliable, and actionable. In addition, ISO 59014 further supports this by defining a standardized product circularity data sheet, facilitating transparency and comparability of circular performance data across value networks.

The business context of circular *PMP systems* is guided by ISO 59010, which offers strategic guidance for developing circular business models. This ensures that our simulation tool not only accounts for technical feasibility but also aligns with economically viable practices and stakeholder incentives.

Together, these standards form a sufficiently coherent and practical foundation for simulating post-manufacturing production in the circular economy. They provide the necessary tools to model responsibilities, quantify environmental and economic outcomes, and ensure seamless information exchange key elements for creating resilient, circular value networks. Additionally, our approach is informed by recent academic developments, such as the IoM article (Carlsson and Nevzorova, 2025) that precedes the emerging Digital Product Passport (DPP) standards, which further reinforce the need for integrated data infrastructures in circular production systems.

Life cycle assessment integration

In the post-manufacturing production model, Life Cycle Assessment plays a central role in defining responsibility domains, evaluating environmental performance, and guiding decision-making across the value network. Anchored in the broader circular economy principles defined by ISO 59004 and operationalized through circular business models as outlined in ISO 59010, LCA offers a structured, systems-based approach for capturing environmental impacts and material flows in the post-manufacturing phase.

We adopt the framework and methodological structure provided by ISO 14040 and ISO 14044. These standards define the phases of an LCA goal and scope definition, LCI analysis, impact assessment (LCIA), and interpretation each of which is carefully integrated into our PMP system. By aligning our simulation tool with these standards, we ensure that all post-manufacturing processes are systematically assessed in terms of their environmental contributions and trade-offs.

Figure 1 illustrates a generic post-manufacturing production system as part of a full circular life cycle model. This includes all relevant activities occurring after initial product manufacture, represented within modular input/output inventories across each life cycle phase. These modules allow for customizable configuration of system boundaries, supporting cradle-to-gate, gate-to-gate, cradle-to-cradle, and user-defined scopes, depending on the specific use case and stakeholder needs.

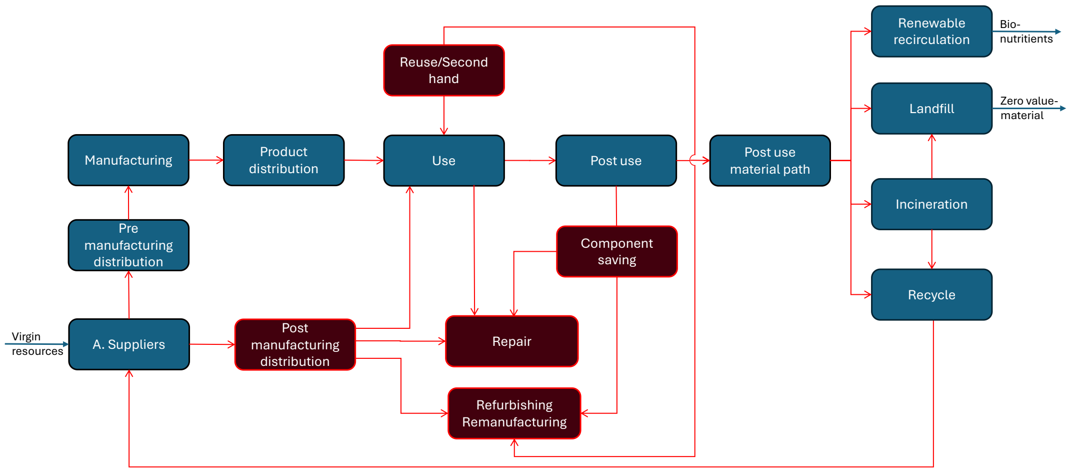

Figure. 1. Flow chart of a generic Post-Manufacturing Production system of a full circular Life cycle product system

To ensure data traceability and facilitate interoperability across systems and actors, we apply ISO/TS 14048. It standardizes the documentation of life cycle inventory data, allowing for transparent, reproducible environmental modeling. Through this approach, every material flow, process input, and output within the post-manufacturing domain is traceably documented in a format that supports digital data exchange and long-term system consistency.

Moreover, the reliability and robustness of environmental information are assured through the use of ISO 14033. This standard addresses the quality and representativeness of quantitative environmental data, enabling rigorous assessment under varying system conditions. It helps ensure that assumptions, proxies, and models reflect real-world conditions as closely as possible and remain valid across different stakeholder perspectives and decision contexts.

Our simulation tool supports customizable impact categories with climate change as the default (IPCC, 2021) allowing for flexible alignment with policy goals or corporate sustainability targets. Users can tailor assessments based on specific environmental concerns or regulatory requirements while remaining fully aligned with the ISO 14040/44 methodological structure.

Ultimately, this LCA integration allows us to define and analyze the environmental responsibilities that arise in the post-manufacturing phase responsibilities that are often overlooked in traditional product assessments. By combining standardized system modeling, transparent data practices, and high-quality quantitative evaluation, we create a rigorous, decision-supportive environment for circular economy strategies at the system level.

Circularity metrics and system configurations

While LCA offers a robust framework for evaluating environmental impacts and resource losses, it is not inherently designed to measure circularity as a performance objective in its own right. To fill this gap, we incorporate the guidance provided by ISO 59020, which offers a standardized approach to circularity performance measurement, and align it with the broader circular economy principles described in ISO 59004. Together, these standards enable a system-level view that distinguishes circular value creation from linear throughput, offering actionable insights into how materials, components, and products circulate within the economy.

ISO 59020 provides the methodological foundation for quantifying circularity through a suite of well-defined indicators. These indicators allow us to assess the extent to which value loops—such as reuse, repair, refurbishment, remanufacturing, component recovery, and recycling—are actively implemented and sustained over time. Figure 2 illustrates our system model for circularity measurement, structured in accordance with ISO 59020. This model captures both material and functional flows, while also distinguishing between linear flows and circular intermediate loops. Such a distinction is vital for clearly identifying where circular strategies succeed and where further intervention is needed.

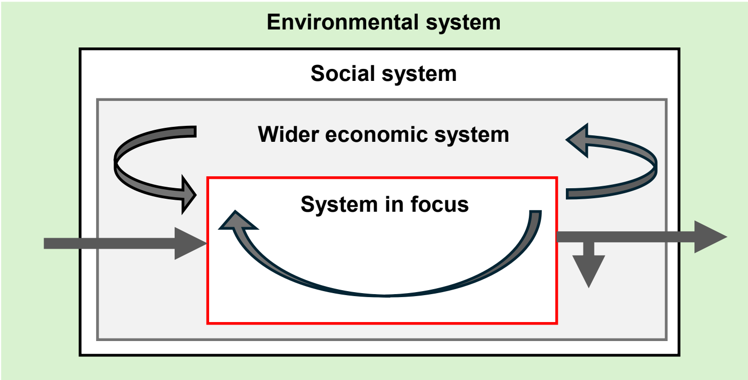

Figure. 2. System model structure for circularity measurement according to ISO 59020

Our simulation tool is built to support flexible functional units or points of value creation, allowing assessments to be configured at the product level, service level, or across entire system configurations. This flexibility is critical for modeling real-world post-manufacturing systems, where products may serve multiple users over time or be integrated into complex service ecosystems. Whether evaluating a single product's reuse cycles or an entire service platform's resource efficiency, the system remains adaptable and standards-aligned.

To reflect actual system behavior and stakeholder dynamics, we integrate configurable flow structures that represent the most common circular strategies. These include prolonged lifetime, reuse, repair, refurbishment, remanufacturing, component recovery, and recycling. Each flow type can be activated or modified depending on the product category, technological constraints, or policy goals, offering a rich set of scenarios for both exploratory analysis and policy simulation.

An important feature of our model is the incorporation of parametrized market behaviors, such as the uptake of second-hand goods, consumer participation in repair schemes, or typical disposal routes. These behavioral parameters reflect the socio-economic realities that influence circular outcomes and allow the model to account for variation in user behavior, infrastructure availability, and regional market maturity.

In contrast to traditional LCA which typically emphasizes resource depletion and waste generation ISO 59020 enables us to focus on value retention and system resilience. By quantifying the effectiveness of circular strategies, we move beyond identifying losses and instead highlight opportunities for improvement and redesign. Circularity, in this context, becomes not only a goal but a measurable property of system performance.

By embedding these circularity metrics into our broader simulation platform, we provide stakeholders with the tools to explore trade-offs, test scenarios, and prioritize interventions. The combination of ISO 59020's measurement indicators with the system thinking of ISO 59004 ensures that circular economy ambitions are translated into actionable system designs and measurable outcomes.

Techno-economic integration

A credible circular economy strategy must be grounded not only in environmental metrics but also in economic feasibility. To this end, our simulation framework integrates techno-economic modeling based on the principles and methodological guidance of ISO/TS 14076 and ISO 14045, complemented by ISO 14033 for the quantitative integrity of environmental and economic data. This integration ensures that each circular intervention is assessed in terms of both its environmental impact and its economic viability across the value chain.

Central to this approach is the incorporation of *life cycle costing (LCC)* methods, as supported by ISO/TS 14076. This allows us to model resource consumption, labor inputs, logistics, infrastructure usage, and other operational cost factors within each circular strategy. ISO 14045 complements this by offering a framework for *eco-efficiency assessment*, which evaluates how effectively a product or system delivers value relative to its environmental impacts. When combined, these standards enable a nuanced, multi-dimensional view of system performance that accounts for both financial and ecological dimensions.

Our economic modules calculate a suite of *circularity-specific indicators*, such as return on investment for remanufacturing, total cost savings from reuse loops, and marginal benefits of material recovery. These indicators are computed for each strategy and phase of the post-manufacturing system, offering a detailed breakdown of how different stakeholders manufacturers, service providers, consumers, recyclers are affected economically. The model supports *actor-specific profitability analysis*, helping identify who benefits, who bears the costs, and where value redistribution or policy support may be necessary.

ISO 14033 plays a crucial role in ensuring that all quantitative data used in these assessments both environmental and economic meet standards for reliability, representativeness, and traceability. This boosts decision confidence by grounding simulations in verified datasets and transparent assumptions, especially when comparing alternative system configurations or planning for long-term investments.

To account for uncertainty and real-world variability, the tool incorporates *sensitivity analysis* features. These allow users to explore how changes in key variables such as material prices, consumer behavior, labor costs, or regulatory shifts affect both economic outcomes and environmental benefits. This is especially useful when simulating disruptive business model transitions, such as moving from product ownership to product-as-a-service models, as described in ISO 59010.

In addition to system-level costing and profitability, our framework supports the *evaluation of externalities,* including economic risks (e.g., supply chain volatility, market acceptance) and system resilience under stress conditions. These aspects are increasingly important for organizations seeking to future-proof their operations and align with broader sustainability and risk management strategies.

Finally, the model aids in mapping *consumer incentives, communication strategies, and value proposition logic,* making it a powerful tool not only for technical analysts but also for business strategists and circular economy planners. By aligning techno-economic modeling with other international standards, we ensure that circularity is not only environmentally sound but also economically robust and actionable across diverse market contexts.

Simulating post-manufacturing production as system in focus

Combined system model

This section introduces the integrated system model that combines environmental and circularity performance frameworks into a unified simulation structure. Figure 3 presents the combined post-manufacturing production system model based on the LCA model (Figure 1) and the system model of circularity performance measurement and assessment (Figure 2). The model is designed to support detailed scenario analysis, capturing the complexity of real-world resource flows, process configurations, stakeholder roles, and value exchanges. It allows users to simulate, evaluate, and optimize diverse circular business strategies while distinguishing the economic impacts on different actors across the value network.

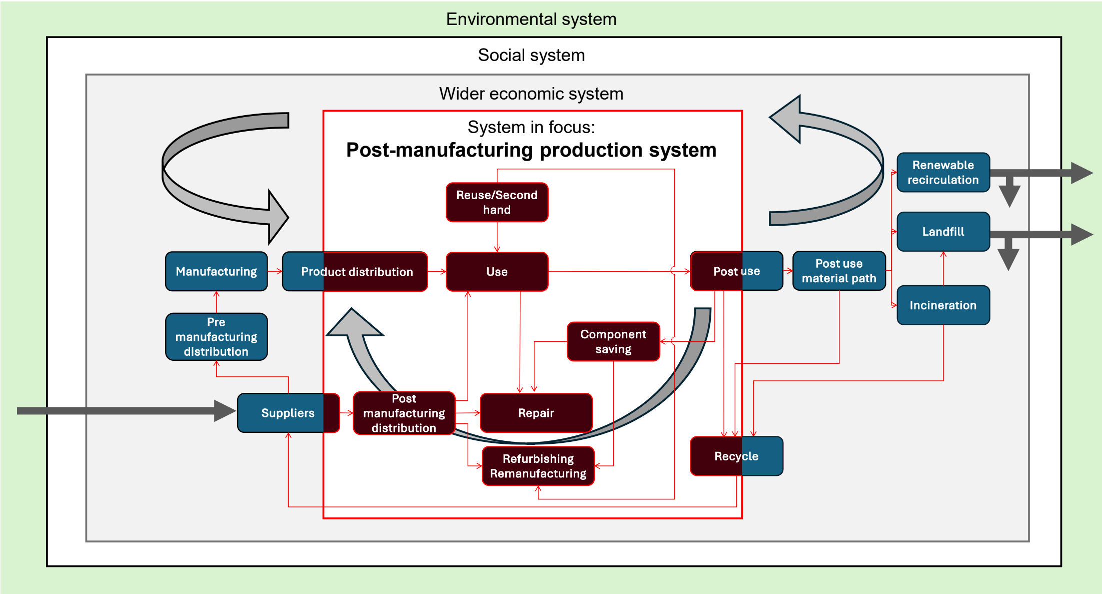

Figure 3. PMP system model based on the LCA model (Figure 1) and the system model of circularity performance measurement and assessment (Figure 2)

By having a highly detailed possibility to parametrize all resource flows, transport distances and modes, process efficiency ratios, as well as any alternative flow path between any processes, any circular business strategy may be modelled as a PMP system. In addition, by also fully parametrizing any process or part of the process to either be allocated as part of, for example, virgin manufacturing or linear waste management or be part of the post-manufacturing system, different stakeholders' economies may be distinguished from each other. This is essential both when simulating the outcome of different circular strategies as well as when monitoring results of implementing such strategies. The distinction of different stakeholders' economies is particularly important to ensure that a value network is based on fair and competitive business models.

Simulation data and calculation architecture

The simulation tool is implemented in Microsoft Excel, having applied a strict structuring discipline to distinguish consumer profiles and scenario specific data on the one hand and generic background data for unit processes and macro level modelling for different geographic and other macro parameters on the other hand. Figure. 4 provides an overview of the transparent logic of the architecture.

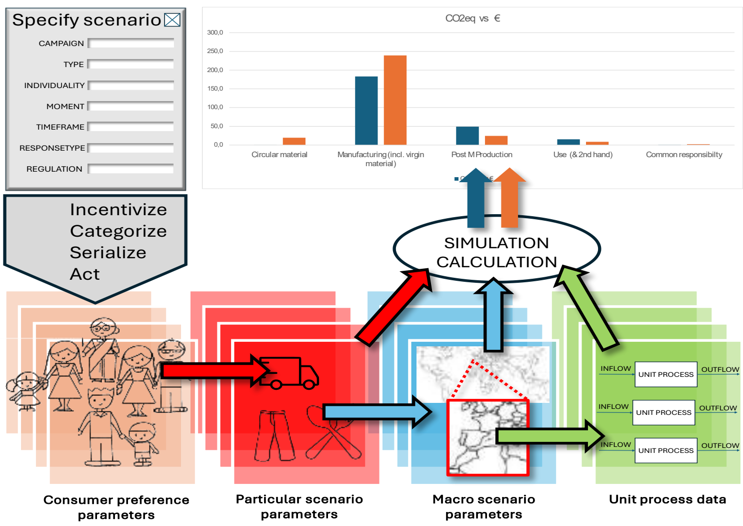

Figure. 4. Architecture of the data modules and workflow from data input to calculation and final result presentation of the PMP simulation

The simulation tool is used as follows. The tool is prepared by the specifics of the PMP system business case and its circular strategy, so that the correct material, geographical specificities, amounts of materials, transport distances, consumer behaviour, and user options, etc., are modelled within relevant ranges of the case. With such a simulation model as a base, a business model or value network designer may run a very large range of different parameterizations with regard to consumer relationships, incentivization systems, changes of business model design, and many other options. Example scenarios may include:

- Parametric representation of consumer repair behavior, component substitution, and reverse logistics efficiency.
- Real-world case study validation uni- or multi-sectoral applicability confirmed across apparel, furniture, construction, machinery etc.
- Ability to simulate how design decisions e.g., remanufacturability, material composition or repair friendliness, affect downstream total PMP system performance or per stakeholder.
- Behavioral economics integration: user choices modeled as decision trees or input probabilities.
- Flexible configuration of end-of-life routes e.g., landfill, incineration, reuse, mechanical recycling or renewable recirculation loops.
- Choices of granularity of particular scenario data, e.g. modes of road transport, source of electric power, labor costs or consumer participation.

The tool supports the application of the principles and the framework of ISO 14033 and therefore provides a platform for trust through verifiability, reliability, representativeness, and comparability of environmental measurements of PMP system performance. Scenarios can be made to highlight e.g. how material efficiency, actor collaboration, and infrastructure readiness affect circularity potential.

By applying the ISO 14033 any dynamic processes or sensitivity analysis, are built consistently and transparently across scenarios. Sensitivity analyses may be trusted to reveal leverage points for policy and investment. Also, serialized dynamic processes representing economic or sustainability consequences from introduced design choices can also be traced based on individual data locations and paths.

In summary, the implementation of the simulation tool is modularized with respect to the key parameters of the PMP system, from highest level of a circular economy systems as described by the ISO 59000 series of standards and the complementary LCA standards, down through the vertical analysis provided by the ISO 14033 standard down to the atomic data bits acquired from well specified measurement systems. In this way the PMP paradigm for post-manufacturing control is as detailed modelled as is any human designed and built manufacturing plant, hence is in principle possible to design and control equally well as such a plant.

Conclusion

This research advances the discourse on circular economy by proposing and validating a comprehensive, standards-based simulation framework for Post-Manufacturing Production (PMP) systems. Grounded in internationally recognized ISO standards, the model bridges critical gaps between linear production assessments and dynamic, real-world circular strategies. By focusing on post-manufacturing phases the framework repositions these activities as intentional, value-creating components of an extended product lifecycle, rather than as peripheral afterthoughts.

Our system is designed not only to evaluate environmental impacts through life cycle assessment but also to integrate circularity metrics and techno-economic factors in a transparent and actionable way. The simulation tool allows stakeholders to explore complex trade-offs, compare linear and circular business models, and assess both environmental and financial implications across entire value networks. It supports real-time scenario analysis, taking into account customer behavior, infrastructure availability, and communication effectiveness throughout the extended product lifecycle.

In formalizing the PMP concept and embedding it within a robust simulation platform, this work lays the foundation for a new generation of tools capable of operationalizing circular economy principles at market scale. The approach aligns circular business model design with sustainability goals, enabling more deliberate, measurable, and profitable circularity strategies. As digital infrastructure and policy frameworks such as Digital Product Passports evolve, the value of such simulation tools will only increase. Our model contributes to this emerging ecosystem by offering a transparent, standards-aligned methodology for driving circularity from design through post-use, ultimately enabling smarter and economically viable circular production, consumption, and recovery systems. Future developments may include integration with digital twins, sensor data, and digital product passports for real-time updates and improved scenario fidelity. ISO/TS 14076 and ISO 14033 will remain central in demonstrating both the economic robustness and environmental verifiability of modeled outcomes.

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A Practice-based Material Exploration of Chitosan Coatings for Sustainable Fashion

Mingsheng Ni

PhD Student

University of the Arts London

United Kingdom

Abstract

The fashion industry thrives on rapid trend cycles, prioritizing aesthetics over durability, which exacerbates environmental issues through excessive textile waste. This study explores the potential of chitosan bio-coatings not merely as functional agents, but as a medium for creating novel, sustainable aesthetics. It positions chitosan as a versatile finish that enhances textile functionality, promotes safe disposability, and introduces new design possibilities. Through a practice-based material exploration, this research investigates various application methods from industrial padding to craft-based dip-coating, screen printing, and direct film casting to create a range of effects, from invisible functional coatings to thick, leather-like textures with embedded color. This approach is critically predicated on the use of natural, biodegradable substrate fabrics, such as cotton, to create a fully compostable garment system. The research evaluates the coating's impact on material properties, functional performance and aesthetic qualities, positioning chitosan as a tool for designing materially responsible and visually innovative fast fashion.

Introduction

The global textile and apparel industry has created a paradox of material longevity and product obsolescence. This model, characterized by accelerated production cycles, accessible low-price points, and rapid trend turnover, has democratized fashion but at a significant environmental cost (Niinimäki *et al*., 2020). The industry's linear 'take-make-dispose' structure results in an estimated 3 percent to 5 percent of global carbon emissions.(Ellen MacArthur Foundation, 2017; McKinsey&Company, 2023). As its market share grows, the fashion industry, including textile and apparel production, has also become the second most polluting sector worldwide (Rathinamoorthy, 2019). This is largely due to the significant demand for natural resources in its production processes (WRAP, 2012).

A fundamental issue is the material composition of these garments. Material production accounts for 25-40% of the industry's total emissions, with upstream activities contributing approximately 70% of the carbon output. (McKinsey & Company, 2020). The pursuit of low costs has led to a heavy reliance on synthetic fibers, particularly polyester, which is non-biodegradable and sheds microplastics (Textile Exchange, 2021). Furthermore, conventional chemical finishes used to impart desirable qualities often rely on toxic substances like PFAS (Bevilacqua *et al*., 2019), contaminating the waste stream and preventing safe biodegradation. Among the stages of FF's lifecycle, prioritizing the use of sustainable materials is essential for reducing the fashion industry's carbon emissions.

Therefore, this research proposes a material-science and design-led intervention to mitigate the resulting environmental damage. The core proposition is to design for a safe and clean end-of-life. This paper explores the development of a fully biodegradable garment system, where a natural textile is enhanced with a functional, non-toxic, and equally biodegradable bio-coating.

This research aims establish chitosan a biodegradable biopolymer as a viable, non-toxic replacement for conventional chemical finishing processes. The primary goal is to validate its functional performance as a sustainable auxiliary material. Following this, the research explores how chitosan can be used as a creative medium to develop a range of surface appearances, incorporating diverse colors and textures. By varying its formulation and application, the study investigates the characteristics of these functional and aesthetic finishes. Critically, this approach enables a safe, clean end-of-life, provided the coating is applied to a compatible biodegradable substrate like cotton. The study is guided by the following research questions:

What functional and aesthetic gains can chitosan coating deliver on bio-based textiles without undermining compostability?

The contribution of this paper is twofold. First, it presents the results of an experimental inquiry into chitosan coatings, culminating in a comparative analysis that maps application techniques to the resulting aesthetic, functional, and performance properties. Second, it offers practical guidance for textile finishing lines on how to implement these bio-based coatings as a viable, sustainable alternative to conventional chemical treatments.

Contextual Reviews

Chitosan, the key ingredient

Chitosan, a derivative of chitin, is the world's second most abundant and renewable biopolymer after cellulose (Rinaudo, 2016). Sourced from crustacean shell waste and and fungal sources, chitosan is also a value-added material from a waste stream, it commercially produced with an estimated 1000 billion tons per year (Bakshi *et al*., 2020). As a naturally derived polysaccharide, chitosan offers several benefits of biorenewable, environmentally friendly, biocompatible, biodegradable, and biofunctional (Zargar *et al*., 2015). The film-forming ability is the key characteristic of chitosan that allows it to be applied as a coating. Under mildly acidic conditions its primary amines are protonated, giving a rare polycationic polysaccharide that forms coherent films through hydrogen bonding and ionic interactions (Rinaudo, 2016). Chitosan films can also be reinforced by nanoscale fillers such as cellulose nanofibres, which improve mechanical strength and reduce brittleness through interfacial bonding (Ifuku & Saimoto, 2012; Azeredo *et al*., 2017). Previous studies confirm that nanocellulose incorporation enhances tensile strength, flexibility, and barrier properties of chitosan-based films (Li et al., 2016; Pereda et al., 2018). In this study, the addition of c-CNF resulted in enhanced tensile behaviour and smoother surfaces when chitosan formulations were applied by direct film-casting onto cotton fabrics in the design exploration route.

Currently, Chitosan and their derivatives are utilized across various fields including food, material science, medicine, textile finishing, cosmetics, water treatment, and agriculture, marking them as a prominent research area in biological sciences (Wei *et al*., 2013). In textile industry, chitosan has been deployed as a thin conformal coating or pretreatment to enhance dye uptake and fixatio, (Julià *et al*., 2000, p. 63; Roy Choudhury, 2014, p. 11), provide UV/antimicrobial finishes (Zhou *et al.*, 2019, p. 11; Yang *et al*.,2020, p. 2521), and contribute nitrogen–phosphorus char formation in flame-retardant (FR) systems (Dong *et al*. (2015, p.225).

However, existing research primarily focuses on its industrial application for durable, long-lasting textiles, often as an invisible treatment. This study re-contextualizes its application in the fast fashion context with biodegradability, functionality and its aesthetic potential.

Natural Cotton as the Substrate

The most common fiber in fashion is the synthetic fiber such as polyester by far, followed by cotton, made up approximately 67% of global fiber production in 2023 (Textile Exchange, 2024). Despite its performance characteristics and cost-efficiency, polyester and other synthetic fabrics are non-biodegradable, the manufacturing of these fibers is an energy-intensive process requiring large amounts of crude oil and releasing emissions which can cause air pollution and respiratory diseases (Rukhaya *et al,* 2021). The environmental benefits of a biodegradable coating are entirely negated if applied to a synthetic fiber. Therefore, this research is grounded in the use of cotton, a natural cellulosic fibers, as the foundation fabric.

As a cellulosic fibre rich in hydroxyl groups, natural cotton has good moisture absorbency, provides a chemically compatible substrate for chitosan finishes (Sinclair, 2015). Due to the similar structure between cotton and chitosan, chitosan has good adsorbability through to cotton van der Waals forces; and it can bind to cellulose through Schiff base reaction between cellulose's reducing end (-CHO) and the amino group of chitosan (Zhou *et al,* 2021). Consequently, chitosan has good fastness when it is used for functional finishing, coating and dyeing of cotton fabrics. The decision to focus on these substrates is deliberate, can positioning the final product as an integrated system where every component is designed for a safe return to the biosphere.

Materials and Methods

Materials

Substrate: Desized 100 % cotton fabric (250g/m2, 0,57mm, Guangzhou Lianjin Textile Products Co., Ltd., China), scoured before treatment; Triton® X-100 (Thermo Scientific, Waltham, MA, USA); Sodium hydroxide (pellets, ≥97%; Fisher Scientific, Loughborough, UK).

Coating: Chitosan (powder, DD 80–95%, viscosity 50–800 mPa·s; SCR, Shanghai, China); glycerol (≥99.5%, AR; SCR, Shanghai, China); carboxylated cellulose nanofibers (diameter 4–10 nm, length ~200 nm, solid 17%; Macklin, Shanghai, China); acetic acid (glacial, ≥99.7%; Fisher Scientific, Loughborough, UK).

Dye: Butterfly pea flowers, roselle tea (local market, China); ethanol (96%, denatured; B2C Retail Ltd, Manchester, UK).

Methods

To capture both technical performance and creative application, the study employed two complementary routes for coating cotton fabrics with chitosan. The scientific validation route used controlled machine coating (padding) followed by standardised testing (SEM, Instron tensile) to provide quantitative data on material behaviour. In parallel, the design exploration route applied low-tech finishing methods (dip-coating, screen-coating, and film casting) and assessed outcomes qualitatively through experiential qualities such as hand feel and surface appearance. This dual approach reflects the project's aim to situate chitosan coatings within both material science and fashion design practice.

Substrate preparation

Cotton fabrics were scoured in a solution containing approximately 6 g/L sodium hydroxide and 4 mL/L Triton® X-100. Treatments were carried out in a laboratory dyeing machine at 100 °C for 60 min. After scouring, fabrics were rinsed thoroughly with warm distilled water until neutral pH was reached and then air-dried at room temperature.

Preparation of chitosan coating solutions

Chitosan solutions were prepared at 5 g/L, 8 g/L, and 10 g/L concentrations in 1% (v/v) acetic acid, under magnetic stirring until homogeneous. For reinforced coatings, c-CNF (5% of chitosan mass) and glycerol (100% of chitosan mass) were added, and the mixture was stirred overnight to ensure homogeneous dispersion.

Scientific validation route

Machine coating: Scoured fabrics were coated using a Roaches EV350 laboratory padder. The roller line speed was set at 2.5 m/min, and the pneumatic nip pressure was adjusted to 1.81 bar. Testing methods. Immediately after padding, the coated fabrics were transferred to a laboratory oven (Mini-Thermo, Roaches International, UK) and cured at 120 °C for 3 min to ensure fixation of the coating.

Scanning electron microscopy (SEM): The surface morphology of the coated fabrics was examined using a scanning electron microscope (Thermo Fisher Scientific, FEI, The Netherlands). Samples were analysed under high vacuum at an accelerating voltage of 10 kV, with a working distance of approximately 10 mm. Micrographs were recorded at magnifications of 500×, 2000×, and 10,000× for each sample in order to investigate both the general surface features and the finer structural details of the coatings.

Tensile testing: The mechanical properties of the coated fabrics were evaluated using a universal testing machine (Instron, system ID: 34SC5B30752, USA). Rectangular specimens with a width of 25 mm were prepared, and eight specimens were tested for each group to ensure statistical reliability. The crosshead speed was set to 50 mm/min.

Design exploration route

Dip-coating in chitosan solutions, and hand screen-coating to create single side coatings.
Direct film casting of chitosan-based formulations onto cotton substrates.

Dye extraction: Dried butterfly pea flowers were ground into powder and extracted in 70% (v/v) aqueous ethanol (ethanol: deionised water = 70:30) at room temperature for 24 h under stirring. The extracts were then left to stand in a fume hood for an additional 48 h to allow partial solvent evaporation, yielding a concentrated semi-solid dye. Dried roselle flowers were ground and extracted in distilled water at 70 °C for 30 min under stirring. The extracts were filtered to remove insoluble residues and used immediately for dyeing.

Results and Discussion

Scientific validation results

SEM morphology
The results of chitosan treated cotton fiber morphology are shown in Figure. 1. The coating evolves from thin and patchy to continuous and then to a thicker and more even layer as concentration increases. At 5 g/L the chitosan layer is thin and discontinuous, the native cotton topography remains visible and many fibre sectors are only lightly covered. At 8 g/L a coherent skin envelops most fibres, shallow grooves are partly filled and the micro-surface appears smoother and more uniform. At 10 g/L the film is thicker and more even across the fibres, and fine microcracks traverse the coating, which aligns with drying shrinkage and the higher brittleness of polysaccharide films at elevated add-on (Rinaudo, 2006).

At the bundle and fabric scale increasing concentration also bonds fibres at contact points. The effect is negligible at 5 g/L, evident at 8 g/L and pronounced at 10 g/L where bridges fill inter-fibre pores and pull fibres into a denser arrangement. This consolidation restricts relative fibre motion, which typically raises stiffness and initial modulus while lowering drape and extensibility, a trade-off widely reported for chitosan finishes and other polysaccharide binders (Zhou, et al, 202; Li et al., 2016). A moderate add-on near 8 g/L is therefore likely to aid yarn cohesion and improve abrasion resistance without excessive brittleness, whereas the thicker cracked film at 10 g/L can introduce stress concentrators and reduce elongation and strength despite greater coverage (Pereda *et al.*, 2018).

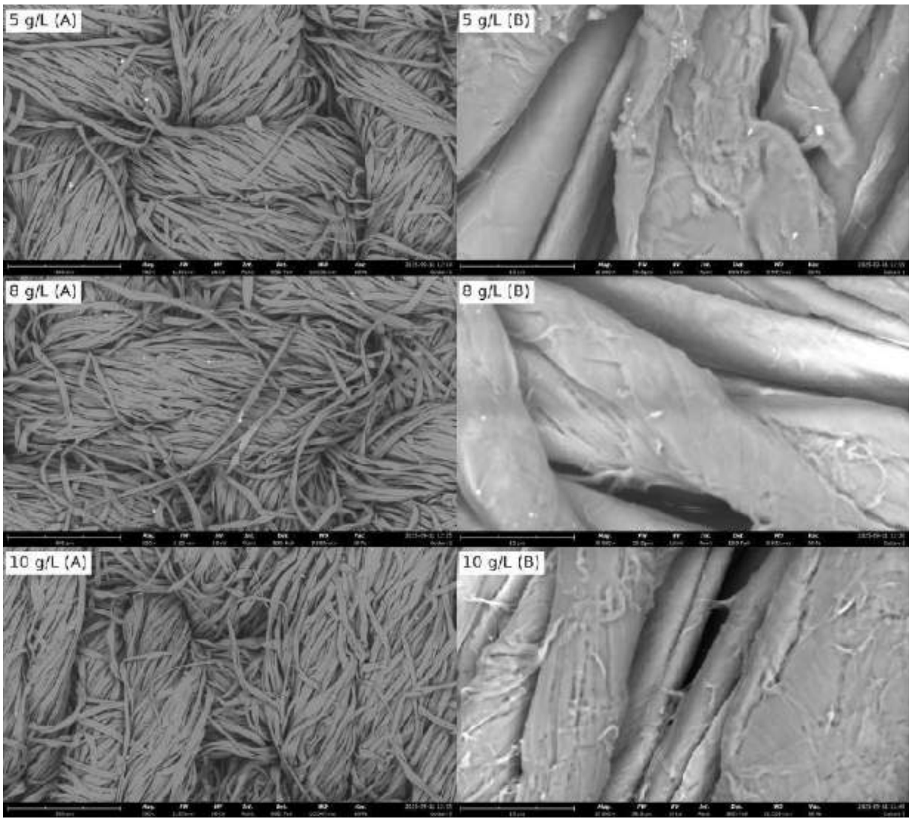

Figure.1 SEM micrographs of chitosan-coated cotton at three solution concentrations (5, 8, and 10 g/L).

Mechanical performance

The strength and breaking elongation of the coated cotton warp directions are presented in Figures. 2. The 5 g/L finish is least favourable mechanically because it sacrifices elongation without a meaningful strength gain. The 8 g/L finish offers the best balance, pairing a measurable rise in peak force with a moderate loss of elongation and a uniform crack-free morphology. The 10 g/L finish consolidates fibres and increases stiffness, giving diminishing returns in strength and the largest drop in elongation. The benefit to peak force was limited by microcracks observed in SEM, which act as stress concentrators rather than load sharers. In this study, the results suggest that 8 g/L is the optimal coating level 8 g/L when aims for a balance between added strength and retained flexibility.

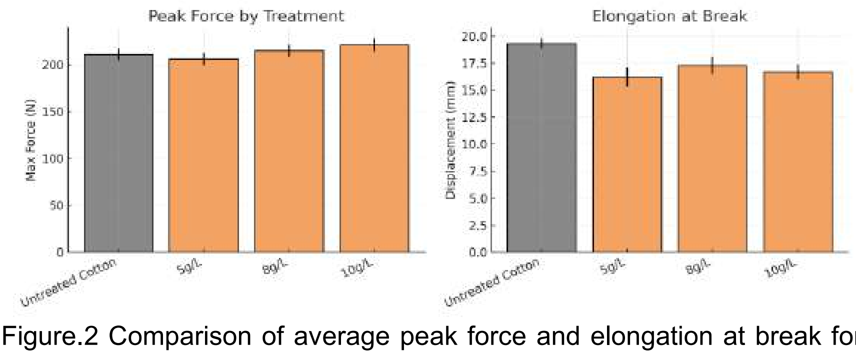

Figure.2 Comparison of average peak force and elongation at break for untreated cotton and cotton treated with 5 g/L, 8 g/L, and 10 g/L chitosan.

The data show a clear trade-off. Chitosan coatings increased peak force as add-on rose, while elongation at break decreased as coating add-on increased. Strength rises with add-on while extensibility falls. From a materials perspective, the strengthening effect of chitosan is due to its role as a binder that bridges fiber contacts and shares load under tension. The decrease in both tensile strength and elongation of cotton after chitosan treatment is due to the fiber damage in acidic conditions (Rahman Bhuiyan *et al*, 2017). This means that while chitosan coatings can enhance the

tensile strength of cotton fabrics, which might be beneficial for load-bearing applications or durability against tearing, one must consider the accompanying loss of extensibility.
The scientific route shows that chitosan coatings alter cotton performance in a predictable, formulation-dependent way. Functionally, the coating behaves as a benign binder on cotton. At appropriate solids it improves cohesion and surface integrity and is expected to support abrasion resistance, while avoiding the persistent polymers used in many conventional finishes.

Design exploration results

The design exploration began with craft-based coating methods, building upon the scientific validation phase. A chitosan concentration of 8 g/L was selected to balance tensile strength and elongation. This formulation, colored with an alcohol-based butterfly pea flower extract, was used for dip-coating and hand screen-coating.

The dip-coating method involved immersing the cotton fabric in the dyed chitosan solution with a liquor ratio of 1 to 30 for 30 minutes, followed by drying on a flat surface. Compared to industrial padding, this method significantly increased the chitosan residue and treatment time. The result was a much stiffer fabric with a hand-feel akin to a material fused with a heavy interlining. This substantial change in character suggests its use for creating structured garments. The chitosan coating dominates the mechanical properties of the final textile; while stress resistance is improved, elasticity is reduced, creating a material that is entirely distinct from the original cotton base.

The hand screen-coating technique, applying the solution with a wire-wound rod within a screen-printing frame, produced a texture intermediate between padding and dip-coating. The initial aim was to create controlled, decorative layers. However, the 8 g/L chitosan solution proved too fluid, easily penetrating the fabric and resulting in an uneven coating. This suggests that for precise patterning, a chitosan mixture with higher concentration and viscosity is required. In both methods, the scoured cotton showed good color uptake from the butterfly pea flower, yielding a blue-purple hue. The color intensity exhibited a clear dependence on treatment time, appearing significantly more vibrant in the dip-coated sample.

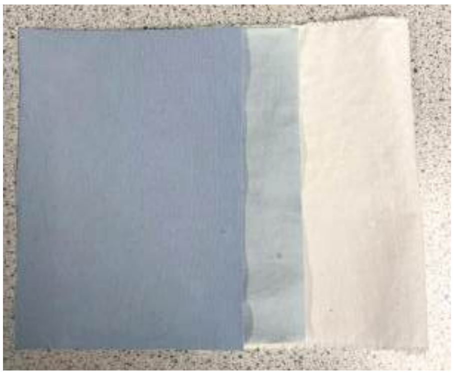

Figure.3 Dip-coating cotton(left), hand screen-coating (middle), untreated cotton (right)

The direct film casting method leverages chitosan's inherent film-forming ability to create a composite material (Figure 4). A chitosan film, plasticized with glycerol, was first cast and dried before being laminated to the cotton fabric (Figure. 5). To bridge the mechanical properties gap between the film and the textile, the formulation was adjusted: glycerol content was increased (100% basis of chitosan) to enhance flexibility, and carboxylated cellulose nanofibers (c-CNF) were added to improve mechanical strength and water resistance. A higher concentration of 10 g/L chitosan was used to reduce the evaporation time.

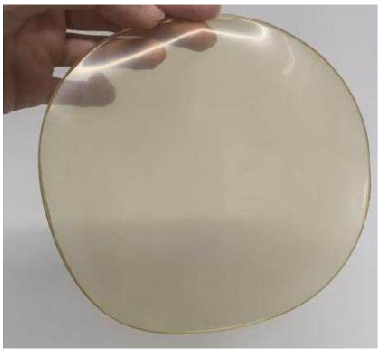

Figure.4 Chitosan film modified by c-CNF Figure.5 Direct film casting cotton (front and back)

The resulting composite fabric functions as a single-layer coated textile, with the reverse side retaining the original cotton texture. The coated surface exhibits a strong gloss, with a tactile quality similar to leather or PVC. It is soft, flexible, and repels water droplets effectively. A slight tendency to curl when at rest was noted, influenced by the properties of the chitosan film. This method also opens up new aesthetic possibilities through integrated dyeing (Figure. 6). The butterfly pea flower yielded a green or blue color depending on drying time and oxidation, while roselle produced a deep black. The final appearance is also influenced by film thickness; thinner films allow the underlying weave of the cotton substrate to remain visible, creating a more textured surface.

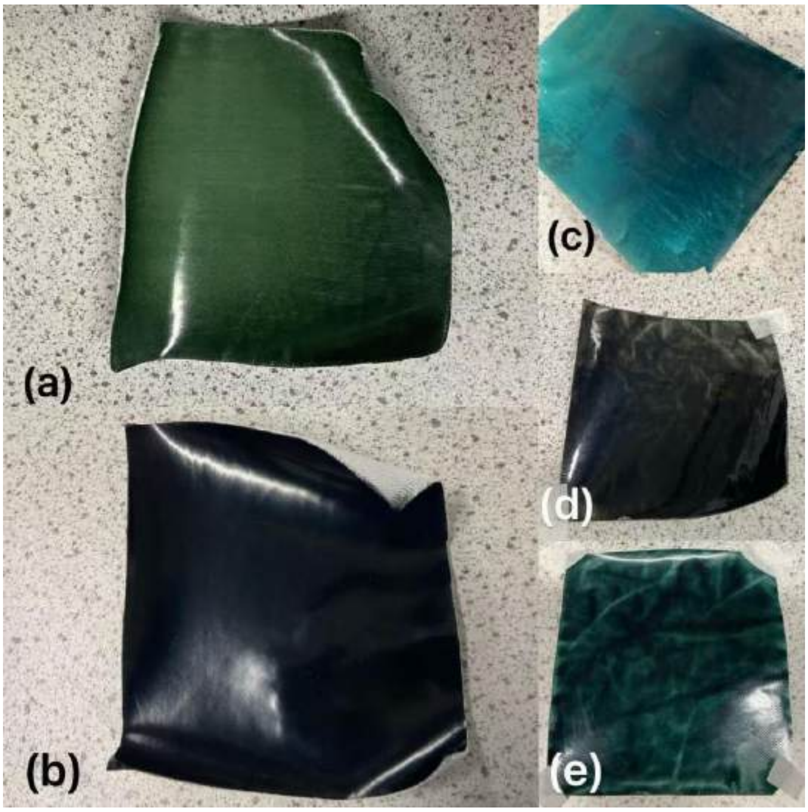

Figure. 6 The direct film casting on cotton with butterfly pea flower
(a), roselle
(b), low oxidation with butterfly pea flower (c), thinner film with roselle (d), thinner film with butterfly pea flower (e)

In summary, the practice-based exploration demonstrates that chitosan is a versatile creative medium. These results confirm that chitosan's role can extend far beyond that of an invisible functional finish, positioning it as a primary material for aesthetic innovation. While this exploration validates the creative potential, the practical viability of these craft-based techniques within an industrial context remains to be addressed.

Conclusion

This research has proposed a design-led methodology for evaluating chitosan not just as a functional coating, but as a versatile medium for creating novel, sustainable aesthetics. The findings demonstrate that a range of techniques can transform a biodegradable substrate into a diverse palette of materials, offering creative, compostable alternatives to petroleum-based finishes.

However, the transition from laboratory exploration to industrial reality still presents barriers. Key barriers to scaling up include technical, economic, and systemic challenges. Technically, formulations must be optimized for industrial machinery, such as developing stable, high-viscosity pastes for rotary screen printing and ensuring consistent results and wash durability. Economically, the cost of chitosan and new processing methods must become competitive with incumbent synthetic polymers. Systemically, the full ecological benefit of a compostable garment can only be realised when paired with the necessary collection and industrial composting infrastructure, which is currently lacking in most regions.

Therefore, the future steps for this research are clear. The immediate focus must be on formulation science to refine coatings for specific industrial applications and on conducting durability and wear trials to establish a clear performance profile.

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Thinking Global, Acting Local: Designing for Regenerative Solutions

Paula Nurminen
RDI Specialist
LAB University of Applied Sciences, Institute of Design and Fine Arts
Finland

Noora Nylander
Senior Lecturer
LAB University of Applied Sciences, Institute of Design and Fine Arts
Finland

Mervi Koistinen
RDI Specialist
LAB University of Applied Sciences, Institute of Design and Fine Arts Finland

Aino Vepsäläinen
Chief Specialist
LAB University of Applied Sciences, Institute of Design and Fine Arts
Finland

Introduction

This study examines how principles of regenerative thinking and the design process can empower novice designers to address sustainability challenges. Regenerative design and nature-based solution creation are explored through the lens of design thinking, with a focus on how novice designers approach urban greenery solutions. The research question is: How can the principles of regenerative thinking, local user-centred tasks, and the design process support novice designers in addressing sustainability challenges, such as climate change? This research will contribute to the debate on fostering innovation and equipping future designers to support sustainable development. The study also demonstrates that designers' efforts toward regenerative solutions can result in concrete actions to green cities.

The research was conducted at the LAB University of Applied Sciences during the Sustainable Design Studio course in 2025, as part of the bachelor-level design degree program. Eighteen students participated in the studio, where the task was to develop regenerative urban green solutions. Three briefs were given to design, focusing on adding urban greenery and preparing for the impact of climate change. The briefs were carried out in collaboration with a local concrete company, which also produces vegetal roofs and walls. For all tasks, benchmarking, user-oriented, and regenerative background research were conducted.

Participants were introduced to design methods and innovative thinking, which they expected to apply to their work. Their design process was examined through learning diaries and interviews to assess how participants understood and used these approaches.

The first brief was to create stormwater stones to reduce the risk of flooding during heavy rainfall by replacing plain, hard surfaces with vegetation and permeable ground. The second brief involved designing a space divider using moss-concrete to enhance urban greenery and create an urban space for both people and non-human users. The third assignment was conducted in collaboration with the horticultural design students at Häme University of Applied Sciences. The task aimed to undertake a multidisciplinary design project that included students from both design and horticulture design. The assignment explored temporary green interventions for urban construction sites and campus areas.

The preliminary study showed that global challenges such as climate change can hinder the design function by appearing too significant, often leading to a sense of overwhelm. This raises the question: Could regenerative design, focusing on local, participatory and user-oriented solutions, provide a more practical and empowering framework for novice designers to engage meaningfully with the problems posed by climate change? Identifying suitable methods for tackling complex challenges helps equip novice designers with the tools and confidence to engage meaningfully with sustainability problems.

How is the design-based approach used in regenerative thinking

A design-based approach promotes regeneration by focusing on relationships and interactions rather than objects in line with ecological thinking. It supports cultural change by changing perspectives, values, behaviour and integrating theory and practice. (Wahl 2016)

Regenerative design is about working in harmony with nature and creating opportunities for it and the broader community to flourish (Veijalainen, Grenman, & Räikkönen, 2023). This requires a change in human behaviour and the replacement of human-centredness with interconnectedness with other living beings and the place where they live (Haggard, Mang 2016). Regenerative design involves principles that learn from the way nature operates, thereby improving the health of the system (Veijalainen, Grenman, & Räikkönen, 2023). According to Haggard and Mang (2016), regenerative thinking supports living beings in co-evolving and discovering their potential in diversity, complexity and creativity, and draws inspiration from biological and ecological systems.

In the Sustainable Design Studio, the first task, stormwater stone, focused on a product-oriented approach. The second task, the moss-concrete space divider, emphasised human-centred and sustainability aspects, encouraging students to consider cultural and spatial contexts. This aligns with regenerative design principles, where designers are expected to create systems that integrate with their surrounding space and cultural context. In the third task, some students participated in a two-day Innovation Challenge, a multidisciplinary design sprint with horticulture design students. In this collaborative context, students developed future-oriented vertical green solutions (e.g., green walls, pillars) for urban environments. The concepts explored the use of circular materials, such as recycled cotton and wool from post-consumer textiles and sheep wool from agricultural side-streams on green solutions.

In this study, we aimed to investigate whether the design thinking process and associated design methods facilitate an understanding of regenerative thinking by creating nature-based solutions for built urban environments. In complex problems, there is no single solution, and therefore knowing the methods helps outline and decompose the process into understandable parts (Kälviäinen, Nylander, 2019). Interviews and process diaries were used to evaluate the development of understanding and its changes.

Data & methods: Integrating regenerative thinking into a design studio

This study was conducted in collaboration with the Sustainable Design Studio course, which involved eighteen second-year bachelor-level design students. The studio ran for four months during Spring 2025 and was structured around three design briefs. The briefs were prepared in collaboration with a regional concrete company that specialises in developing and implementing vegetated roofs and walls.

Throughout the studio, students were introduced to the design process, including user research, ideation, concept development, and modelling techniques, and engaged with a range of design methods, such as brainstorming, prototyping, and material testing. Complementing the practical work, theoretical instruction was provided on regenerative thinking principles, user-centred design approaches, and the role of design in addressing sustainability challenges.

Semi-structured interviews (n = 9) were conducted to explore students' understanding of design methods and regenerative thinking, as well as how their knowledge of these themes evolved during the course. Students participated in interviews in pairs or individually. They also documented their experiences through reflective learning diaries (n = 12). The data collection spanned the entire studio period from January to April 2025, providing insight into the participants' evolving understanding. This qualitative data formed the empirical basis for thematic analysis.

Analysing student experiences through thematic analysis

The qualitative data, consisting of reflective learning diaries and interviews, were analysed using the thematic analysis method. Thematic analysis is an accessible and theoretically flexible interpretative method for analysing qualitative data that facilitates the identification and analysis of themes within a specific dataset (Braun, Clarke 2012). The reflexive approach emphasises that meanings are not passively discovered in the data but actively constructed by the researcher through interpretive engagement (Braun, Clarke & Weate 2016).

Thematic analysis is suitable for a wide range of research questions and datasets of varying sizes. It can be used to identify individual experiences and broader patterns of meaning across participants (Braun, Clarke 2022). In this study, the method enabled an exploration of novice designers' experiences with their design processes and their engagement with regenerative principles and local, user-centred tasks in the context of sustainability challenges.

The analysis followed Braun and Clarke's (2006) six-phase model: becoming familiar with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the documentation. Coding was conducted inductively, with a focus on participants' descriptions of how they applied regenerative design principles and design processes in their work. The reflexive approach enabled the researchers to acknowledge their role in interpretation, facilitating understanding of the participants' learning experiences.

The themes were developed iteratively and in relation to the specific educational context. Attention was given to how design thinking and design methods supported or hindered the development of ecologically grounded and actionable solutions. The analysis revealed conceptual and pedagogical development needs, offering insights into how regenerative thinking can be integrated into design education.

Findings and insights into regenerative design learning

The interviews explored students' experiences of design methodologies and their usefulness in developing renewable solutions, assessed the impact of applied renewable principles on outcomes, and explored how students believe they can contribute to climate change mitigation and adaptation through their work.

Together with the students' learning diaries, the interviews were transcribed and analysed using the thematic analysis method, which revealed four interrelated themes. First, students described how their understanding of regenerative thinking evolved through experiential hands-on engagement, highlighting the importance of the Learning by Doing method. Second, collaboration emerged as a source of confidence and creativity, enabling students to navigate complexity. Third, the ideation phase was identified as both inspiring and overwhelming, highlighting the importance of creative exploration in addressing abstract problems. Ultimately, prototyping and material experimentation play a crucial role in translating regenerative concepts into tangible outcomes, facilitating iterative reflection and embodied learning throughout the design process.

Navigating unfamiliar concepts through practice

Students demonstrated a growing awareness of nature-based design through hands-on engagement in urban green infrastructure with local materials such as moss and recycled fibres. These material-driven tasks helped transform abstract sustainability principles into tangible and site-specific design actions. As one participant reflected: *"I understood what the term 'regenerative' meant, but I had not encountered it in practice before this course. My understanding deepened significantly, and it's something I'll be more likely to bring up in future projects."*

Prototyping emerged as a key strategy for learning and reflection. Students experimented with various biomaterial mixtures and recycled materials to explore ecological implications. In Figure 1, prototyping involved sculpting large-scale mock-ups using natural materials and foam to test structure and scale. One student noted, *"In reality, the design process was not linear. Some methods were used* *simultaneously, and we often jumped between different phases throughout the process".* Prototyping supports both conceptual and practical decision-making. The prototyping phase enabled continuous learning through experimentation, encouraging students to work with unfamiliar methods and materials.

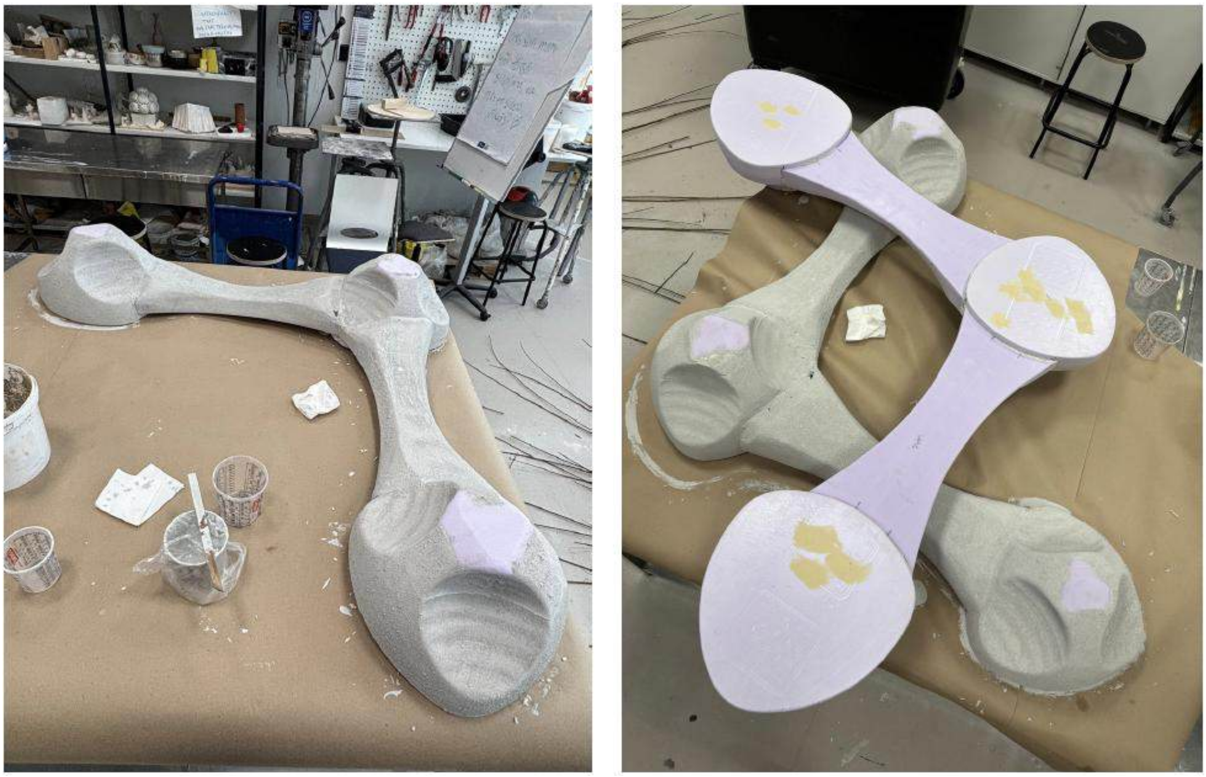

Figure 1. Students prepare a moss-concrete divider prototype. (Figure: Paananen 2025)

Collaboration as a catalyst for confidence and creativity

Collaborative projects and multidisciplinary teamwork were experienced as energising and essential for building creative momentum. Working with peers encouraged idea development, shared responsibility, and emotional support. One student noted the value of collective ideation: *"Sitting at the same table and throwing out all ideas without judgment helped get the creative process going. Once everything was out in the open, we could start focusing and refining together."*

Collaboration also helped students step outside their thinking patterns and recognise alternative perspectives: *"Asking others for feedback helps, especially when working alone, it is easy to get tunnel vision. Even a small comment can point out something important that I had not noticed myself."* These reflections highlight collaboration not only as a social process but as a strategic element in navigating the complexities of sustainability-oriented design.

Ideation as a bridge between complexity and action

Students noted that brainstorming and ideation techniques helped them manage the complexity of climate-related challenges. Ideation served to break inertia and move toward feasible, regenerative solutions. As one student described, *"Mostly, it is about keeping your eyes open. Ideas can come from the strangest things. You need to be able to connect different elements."*

This exploratory mindset was strongly reflected in the early phases of the design process. As illustrated in Figure 2, students' initial sketches often spanned a wide range of formal and conceptual directions. The open nature of visual ideation fostered a sense of creative freedom, lowered the threshold for participation, and allowed students to move smoothly between abstract ideas and concrete design concepts. This also helped to overcome uncertainty: *"At first, I felt unsure how I could come up with something unique or different. Ultimately, the idea for my final concept emerged somewhat by accident. However, the uncertainty about being creative was there in the beginning,"* one student noted. Ideation served as a creative method and a way to cognitively and emotionally engage with the challenges of sustainable design.

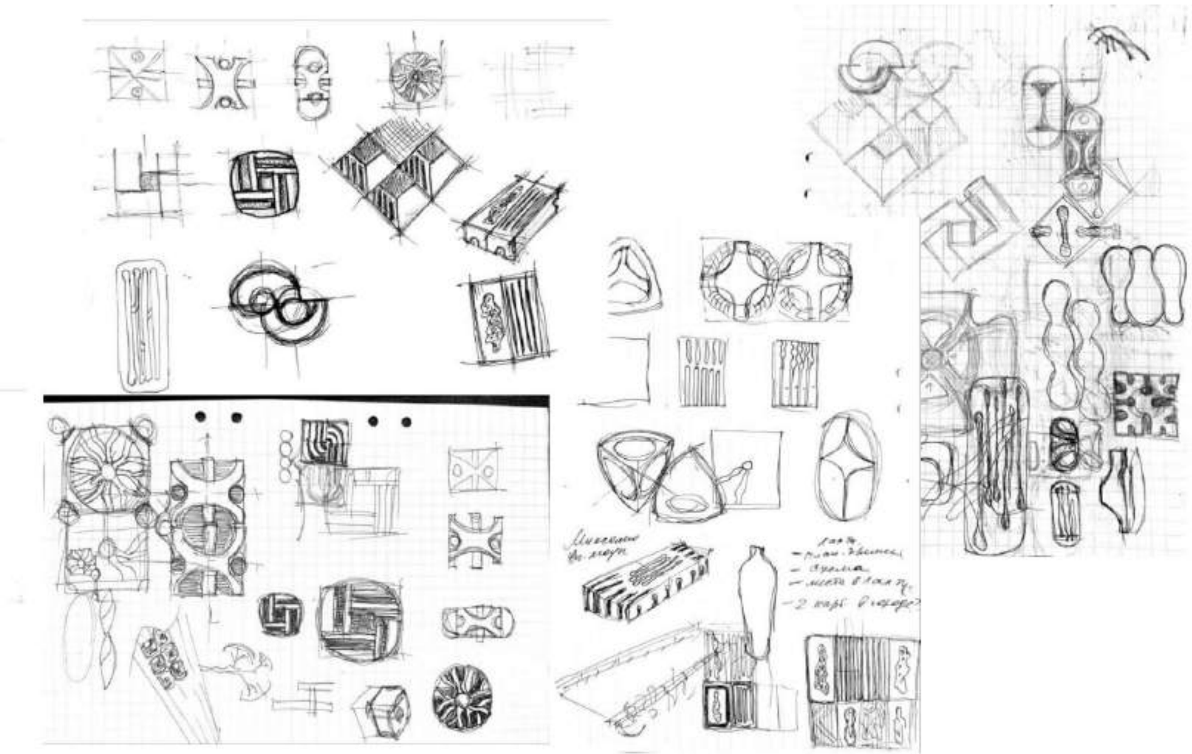

Figure 2. Early ideation sketches by a student exploring form for a moss-concrete space divider. (Figure: Murto 2025)

Grounding regenerative thinking in tangible, local action

Students expressed growing awareness of a nature-based approach, particularly when the design process was rooted in tangible, place-based design tasks. Local, material-based tasks grounded ecological thinking in concrete action. A well-defined brief also helped activate creativity. One participant described: *"I would not say my understanding of sustainability completely changed, but it definitely deepened. At first, I saw it quite superficially just adding some greenery or plants. But the concept turned out to be much more complex than I had initially thought."*

Working with unfamiliar materials also surfaced feelings of uncertainty and pressure, especially early in the process: *"The initial stress was overwhelming. It felt like I knew nothing, and the task seemed far too big for a beginner like me."* However, sustained engagement with regenerative materials such as moss led to new insights: *"During the course, I got to engage more deeply with the moss itself. It felt like I started learning more about the material."* This hands-on learning translated into a stronger sense of agency and future applicability: *"After this course, I feel like I now have something I can bring into future projects, like suggesting the use of moss-concrete … being able to introduce it into the conversation feels valuable."*

As shown in Figure 3, students conducted material tests with concrete, combining recycled fibres in various experimental mixes. These exercises supported both technical learning and conceptual reflection.

Figure 3. Material experiments with concrete. (Figure: Vattula 2025)

The studio as a platform for regenerative thinking

The study identified ways to better integrate regenerative thinking into design practice and contribute to the climate crisis. When the design briefs incorporated the principles of regenerative thinking as part of the task requirements, it did not hinder creativity or successful outcomes. A key factor was the collaborative nature of the work, as challenges were tackled in groups. This enabled continuous progress through co-design, even during challenging moments. As a result, participants also recognised the need for more participatory design processes that include not only people but also nature as an active stakeholder.

Learning by doing in regenerative thinking

Given the scale of the climate challenge and the difficulties that individuals face in tackling it, the focus was on exploring how local solutions can contribute to wider systems. Students learned that local solutions can be scaled up and adapted globally. This insight helped novice designers understand their role as part of the solution. Regenerative thinking principles and local, user-centred tasks can support novice designers in addressing complex sustainability challenges.

Students' understanding of regenerative thinking developed throughout the project; it was first an abstract concept, often viewed as a design objective, such as increasing greenery. Some students found regenerative thinking meaningful, while others hesitated. Participants' evolving understanding of regenerative thinking was rooted in experiential engagement rather than theoretical instruction. Students lacked conceptual clarity; they internalised regenerative principles through direct application in design tasks. Regenerative design, which inherently involves systems thinking and long-term ecological visioning (Reed 2007), may be cognitively overwhelming when introduced through abstract models. Material experimentation and visual exploration played a crucial role in making abstract ecological ideas tangible. By embedding regenerative thinking within hands-on design work, students were able to construct their understanding in ways that were meaningful and actionable.

Peer learning and ideation in sustainability challenges

Collaboration proved to be an enabler of creativity and design progress. Working in pairs and multidisciplinary teams helped students overcome uncertainty and facilitated brainstorming and joint problem-solving. Working with horticultural design students helped to clarify ecological considerations and increased awareness of how nature and green infrastructure contribute to urban well-being. For students, collaboration provides important emotional security and encouragement when dealing with sustainability problems that are inherently complex and multidimensional.

The brainstorming phase supported creative thinking by providing a non-judgmental environment. Students reported that generating multiple ideas, regardless of feasibility, allowed them to mentally "get inside" the problem area. This shows that it is important for sustainability education to allow time and space for divergent thinking before finding solutions.

Figure 4. Space divider with insect hotel functionality. (Figure: Haapanen, Oso & Raatikainen 2025)

Materialising regeneration through localised design

Through practical experiments and prototypes made from natural materials, such as moss-concrete, the students explored how ecological ideas can be translated into practical solutions. Prototyping was a way to test, reflect, and learn. The use of living materials encouraged students to reflect on natural systems, life cycles, and the environmental context of design. Many said that creating and testing ideas in physical form gave them quick and concrete feedback, which supported their learning and decision-making.

Practical implementation was understood to sometimes be limited by budget constraints, material choices (e.g., concrete), or a lack of deeper understanding, such as how moss functions as a living material. Despite these challenges, many students expressed a growing appreciation for nature-based solutions and understood the importance of integrating environmental thinking into the design process. The experience fostered broader thinking about sustainability, biodiversity, and the role of design in creating healthier urban environments.

Figure 5. Stormwater stone, designed by one of the students. (Figure: Kontturi 2025)

The themes demonstrate that innovative thinking in design education for emerging designers benefits from a practical, collaborative, and idea-rich structure. Localised tasks helped contextualise sustainability, and cooperative and reflective activities helped participants cope with complexity. Innovative thinking was best understood through doing, iterating, and reflecting. The results show that practical, collaborative, and contextual design tasks support both cognitive and emotional development in design skills.

Conclusion

In design education, novice designers can be supported in developing practical solutions to global sustainability challenges by breaking down complex problems and processes into understandable tasks. For example, a spatial divider designed as an insect hotel in Figure 4 illustrates how a simple, tangible design can support biodiversity and embody regenerative thinking in a way that is creative, functional, and regenerative. In many projects, regenerative thinking was still treated as an added feature rather than a guiding principle. This highlights the need for further training and reflection on how the design process itself can embody regenerative principles, not just the outcome. The effectiveness of design methods and regenerative thinking depends on how well novice designers understand them. Local urban green solutions can serve as a learning environment for developing sustainable design practices.

This study's findings illustrate how regenerative thinking principles, local tasks, and a well-guided design process can empower novice designers to address sustainability problems. By anchoring learning in tangible solutions, providing structured support, and fostering participatory approaches, design education can offer meaningful pathways to engage with complex environmental issues. This approach helps prepare future designers to create regenerative solutions and equips them with the mindset to make a lasting impact on building sustainable and resilient futures.

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Challenges to the Adoption of Textile Biomaterials and the Potential Role of Digital Supply Chain Platforms

Josef Pacal
Co-Founder
Wonders AI
Materials Science Research Centre
Royal College of Art
United Kingdom

Gareth Loudon
Professor of Innovation Design Engineering
Royal College of Art
United Kingdom

Steve Evans
Director of Research in Industrial Sustainability
Institute for Manufacturing
Cambridge University,
United Kingdom

Sharon Baurley
Professor of Design and Materials
Materials Science Research Centre
Royal College of Art
United Kingdom

Abstract

The damages of the textiles and apparel industry are well documented. Fibre choice has a significant impact. Biomaterials show strong potential for supporting material flows that sustainably integrate waste (Circular Economy); however, their adoption is challenging for brands and suppliers. This qualitative case study investigated brands' and suppliers' experiences, needs, and wishes for a digital procurement platform. Results found four key issues: honesty and transparency in business, a lack of standards, data burden, and communication challenges currently harm the adoption of biomaterials. If developers of the so-called ‘Industry 4.0’ procurement platforms can provide the information needed for decision-making, minimise the burden of maintaining evolving datasets, and facilitate the exchange of swatches, samples and final orders, digital platforms could positively contribute to adopting biomaterials in the textile industry.

Introduction

The damages of the textiles and apparel industry are well documented, with fibre choice having a significant impact. Biomaterials show strong potential for delivering lower production impacts while supporting material flows that sustainably integrate waste flows (Circular Economy). However, their adoption can be challenging for brands and suppliers. This qualitative case study investigated brands' and suppliers' experiences to identify the challenges in adoption of biomaterials, focusing on the needs and wishes that could inform a digital platform. The study considered factors ranging from technology to honesty and transparency, standards, data, and communication.

Literature Review

Biomaterials show potential for the Circular Economy (Ribul et al., 2021) as they derive from a natural origin, are durable, and naturally decompose. (Costa et al., 2020; Dissanayake and Weerasinghe, 2021). Biomaterials can also be produced from renewable resources and replace traditional petroleum-based textiles in existing processes (Glew et al. 2012; Egan and Salmon 2021). Yet biomaterials suffer from slow adoption, with multiple studies offering rationale for this. Biomaterial viability is currently difficult to evaluate due to the need for comparable testing standards and sample availability. In addition, independent research assessment of impact at scale and performance is lacking (Thakker and Sun 2020) as many suppliers fail to report the impact of biomaterials (Torres et al. 2020).

Rognoli et al. (2022) highlight the industry's strong focus on requiring biomaterials to directly match the properties of existing materials. Glew et al. (2012) also discuss concerns about competition with food crops. Most biomaterials are in early Technology Readiness Levels (TRLs), with unanswered questions around cost, scalability, sustainability, and performance (Ghosh et al., 2023; D'Itria et al., 2021). In addition, regulations have favoured fossil-based materials (Ladu et al. 2019). Table 1 below summaries some of the issues with biomaterials highlighted in the literature.

Topic	Source(s)
Technology readiness	(Roos et al. 2019)
Cost	(Morrow et al. 2023; Ghosh et al. 2023)
Scalability	(Morrow et al. 2023; D'Itria et al. 2021)
Performance issues	(Rajesh 2023; Ghosh et al. 2023)
Lack of consistent terminology	(Fletcher et al. 2021)
Regulatory challenges	(Rajesh 2023; Ladu et al. 2019)
Research and development funding challenges	(Charnley et al. 2024)
Sustainability scepticism	(Egan and Salmon 2021)
Consumer perceptions	(Petreca et al. 2022; Fletcher et al. 2021)
Competition with food crops	(Glew et al. 2012)

Table 1. Identified gaps or challenges with biomaterials

Many authors promote the use of procurement platforms as a solution, hence the focus on so-called ‘Industry 4.0’ procurement platforms as key stakeholders for this research, as they hold the potential to provide the information needed to increase the adoption of biomaterials.

Methodology

This qualitative study utilises design research methods to seek novel perspectives on suppliers' and brands' experiences with biomaterials and the platforms they use. This approach explicitly charts a path from practical problems to desired futures (Peffers et al., 2007). Design research aids strategy with deep, communicable, user-centred insights that empower innovation in nascent environments (Holtzblatt and Holtzblatt 2014). Methodological limitations lie in reduced generalizability and bias from the small sample size (Collins et al. 2004).

Methodology Overview

A qualitative approach composed of semi-structured interviews was chosen. The quality of the findings was validated via an interview with a procurement consultant. Semi-structured interviews were used to gather participants’ internal perspectives via open-ended conversations (Wengraf, 2001).

Participants & Sourcing

Twelve (12) participants were invited. Eight (8) responded. A recommended minimum of five participants was reached, with six (6) professionals joining (Nielsen and Landauer, 1993). Participants were sourced by ‘cold outreach’ and snowball sampling to minimise bias. Ethical approval was granted by the ethics board at the Royal College of Art (RCA) and all participants completed consent forms before participating in the study.

The following groups were represented: One (1) Material Supplier, one (1) Procurement Consultant, one (1) Freelance designer working with large performance brands, and three (3) represented Apparel Brands's perspectives. Participants represented senior roles at major brands and established start-ups across footwear, outdoor and performance, luxury accessories, and women’s boutique apparel sectors.

Thematic analysis

Computer-aided thematic analysis helped manage the large amounts of qualitative data (Wengraf, 2001, page 28), coding emergent themes on an ongoing basis (Behar-Horenstein, 2018). Theoretical constructs were refined with each interview to corroborate their potential strength (Eisenhardt, 1989). This study does not attempt to construct Grounded Theory due to the limited sample, interdisciplinarity, and geographical scope (Behar-Horenstein, 2018).

Results and Discussion

Business Motivations

Table 2 summarises the key motivations highlighted by participants for adopting biomaterials.

+	Pushing circularity forward (traceability, biomaterial awareness, reducing petroleum-based materials)
+	Positively driving an industry shift
+	Maintaining competitiveness

+	Legislative and Compliance pressure
+	Financial promise and opportunity
+	Reducing petroleum-based material use
+	Reducing animal cruelty
+	Continuing heritage
+	De-globalizing and re-localising

Table 2. Business motivations for participating in the sustainability agenda

Pain points and blockers

Participants highlighted the following key pain points in procuring and using biomaterials and how that introduces friction, making action difficult and making the use of biomaterials less likely.

- Misalignment of expectations around biomaterials and their commercial readiness: The most common pain is around expectations and commercial readiness; Some brands "won't talk about a product unless [they] have a final test result on a finished product showing us what is in [it]" (Brand participant 1). Participants expect biomaterials to perform equally to traditional materials they are replacing. Currently, these expectations are often not met.
- Clarity and honesty about material composition and performance: "When it comes to plastics, it's tough to trace the bio content as chemically it's the same" (Brand Participant 1). Suppliers know that "there's no way of testing the [actual] content" (Brand Participant 2). Which opens opportunities for misbehaviour mentioned by several participants. This is also exacerbated by a sentiment that they cannot trust certifications. Some participants shared stories of purchasing "sustainable materials" with a promise of certain percentage of "bio-content" or "recycled content", only later finding that to not be true. Another common comment related to colour fastness and abrasion resistance of alternative (biomaterial) leathers, where the materials did not match promised performance. Some participants commented that some suppliers misrepresent such parameters or engage in optimistic thinking and overpromising. On the other hand, the interview with a biomaterial supplier shared a pain of having to "debunk myths and overly optimistic expectations". This suggests that the industry would benefit from systems and a philosophy that encourages greater transparency between the parties.
- Difficulties managing communication (both ways) and finding shared language: All participants mentioned challenges with timely, transparent communication and shared language. Brand participant 2 mentioned that "[redacted] was so overwhelmed by demand it took them almost a year to send us a sample". Communication is clearly a challenge as the number of inquiries both ways is said to be "difficult to manage". Getting timely responses seems to be difficult, as one participant put it, they "waited almost two years to get samples". Another common pain is finding a "shared vocabulary" as involved parties are either technical, creative, or business in background. It would be beneficial to find ways to facilitate structured and honest conversations between the parties, preferably away from their email.
- Burden of maintaining information on biomaterials: Current practice seems to be that of manual upkeep of spreadsheets containing all information on used materials. This has proven difficult to keep up to date as biomaterials, and their properties, are constantly changing. Participants highlighted that it would be useful to have a platform that can reduce this burden of 'double-recording' by providing a single source of truth about materials.

Participants highlighted the following blockers that can prevent action.

- Lack of biomaterial availability, price, and commercial readiness: The first and most cited blocker was the readiness of biomaterials. That is biomaterials' readiness to fulfil expectations of commercial textiles production. Whether that be performance or manufacturing integration. Second is availability. Good quality biomaterials are difficult to discover and order. It appears that a number of innovators are creating biomaterials but are at an early stage of development. Third is price. "Sustainable materials tend to be more expensive for various reasons" - cost, low production volumes, or raw material input (Freelance participant), their availability is limited, and "they're not available [locally]" driving high import costs (Brand participant 3). A biomaterials platform needs to increase openness regarding availability and readiness, which in turn could lead to the establishment of research and development relationships that could help small suppliers mature their stock, and brands participate in systemically meaningful use of smaller product runs.
- Lack of performance compared to currently used materials: being the biomaterial lack of performance; or conversely the brands' expectations that biomaterials will perform equally to traditional materials. This was highlighted as being particularly problematic in footwear and performance-wear: "products were cracking after a short while in consumer's hands" (Brand participant 2).
- Low production volumes, challenges with minimum order quantities (both high or low): Production volumes and 'Minimum Order Quantities' pose a double-edged issue. Working with "a big brand, then they need quite a lot" (Freelance participant), this may be challenging to supply. However, smaller orders manufactured for emergent sustainable brands are often not profitable for Suppliers. For example, brand participant 1 highlighted that they manufacture "1,5 million shoes", which requires large amounts of consistently performing leather. Conversely, from an "Early" Supplier's perspective, it would be useful to find brands who are looking for smaller production runs and are open to using such materials experimentally.
- Trade secrets and exclusivity agreements limiting the availability of the most promising materials: Another commonly cited blocker is around trade secrets, non-disclosure practices, and exclusivity. Brand participant 1 cited that they could not adopt a biomaterial because "Adidas or Nike snatches them first." The interviewed supplier specifically cited that they "obviously did not sign an exclusivity agreement," with their partner to keep their development open. Likewise, they said that they wish for "sharing practices," and emphasized challenges with having to "reverse engineer" competitors' methods to learn. There is therefore an apparent need to encourage industry openness and collaboration, to accelerate the transition towards a more sustainable textiles industry. The findings also suggest that exclusivity agreements hinder industry progress and are frustrating for both brands and suppliers.

Overall, biomaterials are receiving a mixed reception due to several challenges—many related to process difficulties not connected to their technology readiness. A new biomaterials management platform can potentially address emergent needs. However, there is a critical misalignment of expectations about biomaterials' performance and availability. Brands and designers seem to see novel materials as a 1-to-1 replacement for current stock (i.e., matching the performance of animal leather). Partly, suppliers' hope to secure contracts may overpromise on such hopes. There were accounts given of actors who actively misrepresented bio-material composition or performance (e.g., false promises on colour fastness or disclosed bio/recycled content).

Challenges in communication, standardization and consistency prevent effective collaboration. Maintaining non-standard repositories of constantly evolving information is challenging. Operations are currently managed across several unsuitable platforms (e.g., WhatsApp). Further, a lack of tactile presentation and experiences limits designers' ability to envision biomaterial-based products, which is essential considering their qualitative differences. Trade secrets and exclusivity agreements are also frustrating for both sides—again limiting broad adoption.

Some brands think suppliers will not share material information, but the interviewed supplier did so readily and advocated for industry transparency, motivated by the desire to disrupt harmful industrial practices. Wishful thinking and myths about biomaterials also contribute (i.e., the readiness of biomaterial composting infrastructure). The industry must increase transparency to create realistic expectations of novel biomaterials and reduce frustration on both sides of the exchange.

Biomaterial procurement platforms are uniquely positioned to encourage transparency. They enforce structured benchmarks of “what sustainability looks like” and even address issues like multilateral procurement to aid with minimum order-quantity challenges.

Conclusions and Future Research

The study suggests that developers of biomaterials platforms should focus on facilitating an honest and open exchange of all data needed for decision-making, minimising the burden of keeping data up to date, and enabling the exchange of swatches, samples, and final orders. The somewhat adversarial relationship between biomaterial suppliers and clothing brands must evolve into one based on collaboration and sharing. Suppliers will benefit from cost-effective testing grounds to aid development, and brands will gain much-needed storytelling of their contribution to sustainability. They will also have a stake in developing materials to fit performance requirements.

As this qualitative study utilized a limited sample of participants, further research is needed to validate the generalizability of our findings.

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Traceability 5.0: Why Digital Product Passports Will Reshape Consumer Trust and Business Models

Anand Rao

Partner

Tiger Analytics

United Kingdom

Abhijit Chatterjee

Senior Principal

LTIMindtree

United Kingdom

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Abstract

Traceability 5.0 redefines the transparency of the product lifecycle by combining human-centric principles of Industry 5.0 with emerging technologies like blockchain, artificial intelligence (AI), the Internet of Things (IoT), and Digital Product Passports (DPPs). This paper explores DPPs as tools for providing real-time, reliable data on product origin, carbon emissions, and circularity across the lifecycle. It discusses their role in regulatory compliance with the European Green Deal and ESPR, building consumer trust, and enabling circular economy models. Case studies highlight how blockchain-based DPPs help cut waste, support ethical supply chains, and foster economic inclusion. It provides a blueprint for the underlying technology of Traceability 5.0, focusing on decentralized ledgers, smart contracts, and AI-driven analytics as the backbone for a resilient, compliant, and transparent supply chain. In a world of shifting sustainability policies, DPPs are set to be key in bridging the gap between corporate strategy and regulatory & consumer demands.

Introduction

In today's rapidly transforming world, there is a global paradigm shift underway from a linear to a more circular, regenerative economy. The prevailing economic model, the linear economy, has been severely damaging to the environment. Based on a *'take, make, dispose'* pattern, its foundation on the exploitation of non-renewable resources has been resulting in resource depletion, pollution and climate change, making it clear that this model is no longer fit for purpose. By contrast, the circular economy (CE) takes a different approach to designing economic activity. Based on a *'grow, share, and regenerate'* model, the CE aims to decouple growth from the exploitation of natural resources. With these goals in mind, it is critical to develop a sustainable and trusted method of reporting in order to accelerate the shift towards a CE.

The European Green Deal has clearly defined the need for a sustainable and circular approach to the entire life cycle of products. A future legislative package, including the Eco-design for Sustainable Products Regulation (ESPR), as well as "New Battery Regulation", will require manufacturers to make use of digital product passports (DPP) in order to increase the sustainability, circularity, and resource efficiency of batteries, textiles, electronics and other products, such as buildings and construction materials. They must prove in depth knowledge of their supply chains' CO_2 emissions, raw material consumption, circularity of products, as well as evidence of ESG compliance.

Understanding the Circular Economy

The circular economy (CE) is a systemic model of economic development that is regenerative by intention and design. In contrast to a linear economy, which assumes finite resources and resources used in the production processes become waste, a CE is regenerative by design and works to gradually decouple growth from the consumption of finite resources. It operates on three main principles:

- Design out waste and pollution
- Keep products and materials in use
- Regenerate natural systems

The CE places a strong emphasis on the reuse, remanufacturing, and recycling of products in an attempt to keep them in use for as long as possible and, ultimately, create a closed-loop system with no waste at all. The main principles of the CE are derived from the three R's: *reduce, reuse*, and *recycle*. In an ideal CE system, waste and pollution would be minimised by designing products that can be easily repaired, reused, or recycled at the end of their useful life. This is done through the use of sustainable materials, design for disassembly, and closed-loop supply chains.

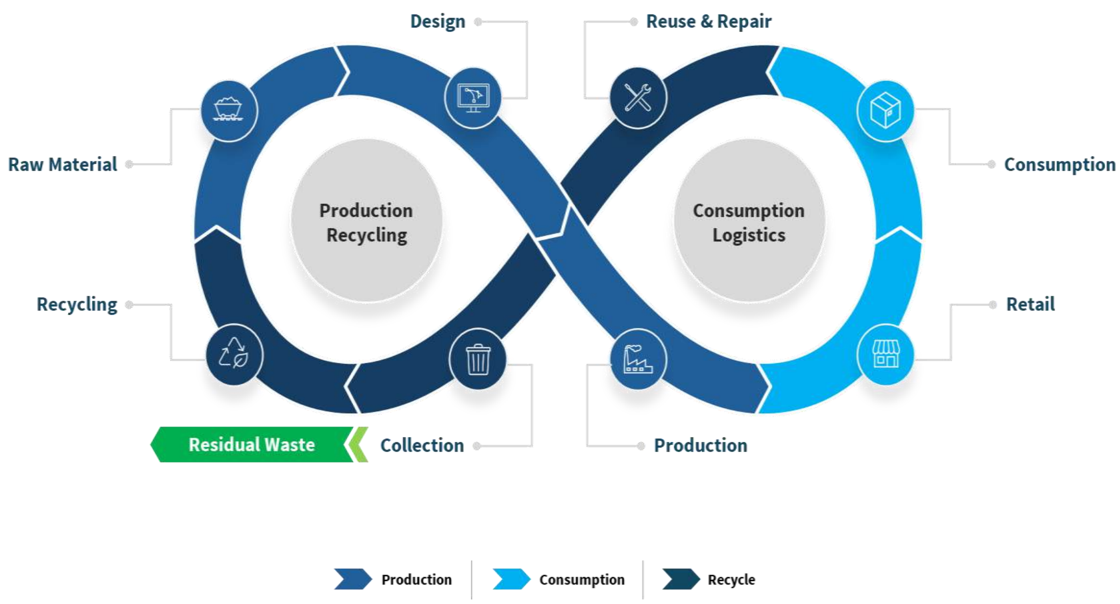

Figure 1 - Principle of Circular Economy

Challenges in implementing Circular Economy

Implementing a CE presents several structural and systemic challenges that hinder its widespread adoption.

One of the most important is the rebound effect. It is possible that resource productivity improvements will, in the best case, not lead to the reduction of resource consumption and even, in the worst case, lead to resource consumption growth [1]. As an example of this, due to savings in one area there may be an increase in demand for consumption in other areas.

Cost is another important barrier. In the short term, transition costs can burden the resources of an organization or economic entity, even though CE offers greater long-term benefits. Transition costs include capital investments in the modernization of production, processing, and storage facilities, product re-engineering, training of personnel, and other costs, the solution of which may be ensured by additional financial resources from the state or market.

Additionally, regulatory and market-related barriers can impede progress. A large number of existing subsidies for fossil fuels (carbon economy) represent a direct obstacle to any increase in the competitiveness of alternative energy sources and circular business models.

Definition and the Role of Blockchain in the Circular Economy

Blockchain has the potential to be one of the powerful technologies supporting the realization of the CE. By its nature, being a decentralized and distributed digital ledger, it is characterized by being transparent, immutable [4], and, of course, decentralized. All transactions are recorded on a peer-to-peer network, and each block of data is verified and securely linked in a chain to previous transactions, forming an auditable, transparent, and trustable data record, where every entry in the database cannot be altered by any central authority. Here's how:

Transparency and Traceability
A common problem in many CE models is the lack of transparency and traceability in complex supply chains. Blockchain allows for end-to-end traceability of a product's life cycle, from raw material extraction, production and distribution to its use, recycling, or disposal. This level of traceability allows for more responsible resource use, easier compliance with environmental regulations, and fewer opportunities for fraud or misreporting.

Enhanced Resource Management
Blockchain technology can also be applied to improve resource management by incorporating smart contracts. Smart contracts are self-executing protocols that are embedded into the blockchain and can be used to automate sustainability-related processes, such as verifying the return of recyclable materials or initiating a carbon offset transaction. This automation allows for more efficient use of resources and streamlines sustainability efforts.

Incentivizing Sustainable Practices
Blockchain is also being used as a method of incentivising sustainable behaviour. Token based systems developed on a blockchain platform can reward consumers and businesses for participating in sustainability activities. This could include recycling initiatives or purchasing from more sustainable suppliers. The tokens can then be traded for goods, services or additional sustainability incentives, creating a closed loop feedback system.

Reducing Waste and Promoting Circular Supply Chains
Blockchain also has the potential to support the design and implementation of circular supply chains, where materials are kept in a continuous cycle of use and reuse. By allowing for the real-time sharing and verification of information among different stakeholders in the supply chain, blockchain can enable more collaborative and transparent decision-making. This, in turn, could lead to the development of new, more sustainable and resource-efficient business models.

Core Attributes
On a technical level, the fundamental properties of the blockchain such as decentralization, immutability, consensus mechanisms, and programmable smart contracts also provide solutions to tackle information asymmetries and improve traceability in relevant industries such as pharmaceutical, fashion, and rare earth materials [6]. Key properties:

- Decentralization: Eliminates reliance on a single point of control, reducing vulnerability to systemic failures or malicious attacks [4][5]
- Immutability: Once recorded, data cannot be altered retroactively, ensuring a tamper-proof audit trail [4][6]
- Consensus Mechanisms: Transactions are validated through protocols like Proof of Work (PoW) or Practical Byzantine Fault Tolerance (PBFT), ensuring agreement among network participants [5]
- Smart Contracts: Self-executing agreements encoded on the blockchain that automate processes when predefined conditions are met [4][3]

Blockchain can help scale the CE by enabling transparent tracking, automating compliance, and incentivizing sustainability. As supply chains adopt blockchain, it can boost accountability and support global regenerative economic models.

The Emerging Role of Quantum in Enabling Circular Future (additional view)

Quantum technology is emerging as a powerful enabler of the circular economy, particularly when integrated with blockchain to enhance transparency, efficiency, and trust across product lifecycles. Quantum optimization techniques, such as QAOA and quantum annealing, can rapidly process complex datasets related to material recyclability, lifecycle impact, and logistics, while blockchain ensures that these insights are securely recorded and traceable across stakeholders. Quantum machine learning can simulate thousands of sustainable packaging or production configurations, and once optimal designs are identified, blockchain can immutably log each step, from sourcing to reuse, enabling real-time, verifiable circularity. In waste management, quantum-enhanced algorithms can analyse high velocity data from IoT devices to optimize resource flows and predict carbon emissions, while blockchain provides a tamper-proof audit trail of material movements. This synergy of quantum intelligence and decentralized trust offers a future-proof foundation for building scalable, transparent, and regenerative circular economy models. Quantum Machine Learning can help to detect anomaly like fake certificates, blacklisted ports and altered product IDs and Variational Quantum classifiers (VQC) can help to flag suspicious trade routes and recycling claims.

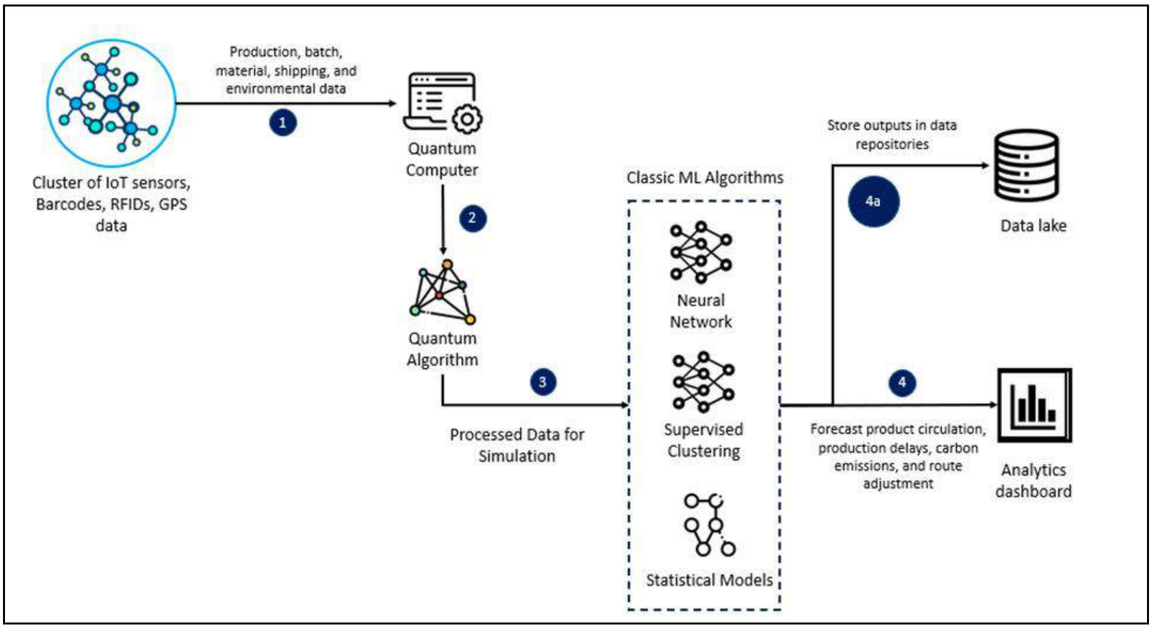

Figure 2 - View of Quantum Technology in action

Integrating Technical Architecture components for end-to-end traceability in Circular Supply Chains

Achieving end-to-end traceability in circular supply chains requires a robust, interoperable reference architecture that connects and aligns various digital components. The following architecture outlines the key elements needed for effective traceability.

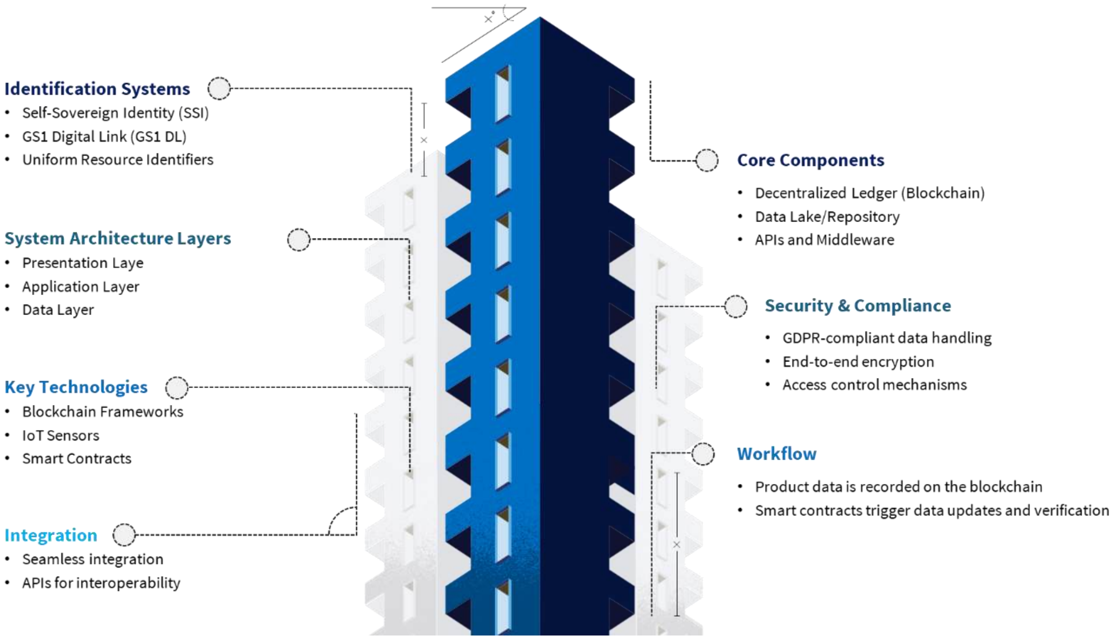

Figure 3 - Architectural components of traceability framework

- **Core Infrastructure Components:** Core to the traceability system is the decentralized ledger (blockchain) as an immutable and transparent source of truth for product data across its lifecycle, alongside a centralized data repository or data lake for handling high-volume structured and unstructured data related to raw materials, production processes, and lifecycle events. Additionally, APIs (application programming interfaces) and middleware enable messaging across different heterogeneous systems, such as ERP (enterprise resource planning), CRM (customer relationship management), and blockchain, for data exchange and interoperability.
- **Enabling Technologies:** The adoption of traceability is enabled by various technologies. Blockchain technologies like Hyperledger Fabric, Ethereum, and Corda are being utilized to provide secure and scalable systems for distributed data recording. IoT sensors are used to capture real-time data on environmental and operational conditions throughout a product's lifecycle. Smart contracts, self-executing digital contracts, are being used to automate data validation and enforce traceability protocols based on predefined conditions.
- **System Architecture Layers:** The traceability solution is based on a layered architecture. The presentation layer includes the user interfaces, which are available to consumers, regulators, and manufacturers. This layer offers visualizations and provides access to verifiable data. The application layer contains the business logic for the authentication of the product, lifecycle monitoring, and compliance with regulatory requirements. The data layer is at the bottom of the architecture, and it includes decentralized databases and blockchain networks that ensure data provenance and integrity.
- **Identification and Interoperability Systems:** Traceability systems must have strong identification measures in place, like serial numbers, QR codes or RFID tags, which can be used to map physical products to digital information. APIs facilitate integration between stakeholders, so data can be securely transferred between platforms and organizations.
- **Integration Mechanism:** To enable end-to-end visibility of product lifecycles, the integration with existing and new supply chain management platforms is required. APIs play a pivotal role in this integration, allowing the ingestion and distribution of traceability information to the participants of the ecosystem for coordinated and transparent processes.
- **Security and Regulatory Compliance:** Supply chain information is often sensitive, so supply chain systems are expected to be compliant with GDPR as well as end-to-end encryption, role-based access, and other common cybersecurity practices.

- **Workflow and Data Lifecycle Management:** Traceability workflows consist of blockchain-based product data recording at key stages of the product lifecycle. Smart contracts are used to trigger automated data updates and validations in real-time, while stakeholders read product credentials and sustainability metadata from DPP web or mobile interfaces.

This enables a secure, end-to-end information supply from material procurement, via production and distribution, to the use and recycling of the product, ensuring data integrity and transparency in the value chain.

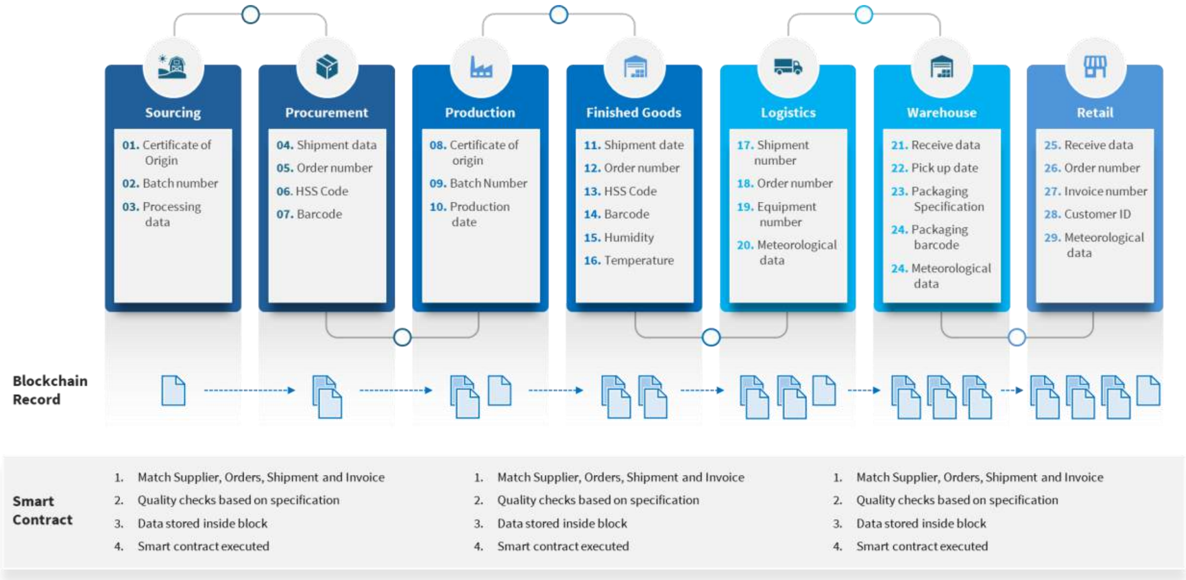

Figure 4 - End to end workflow through blockchain technology*

Blockchain enables seamless integration and sharing of production, material, shipping, and environmental data across the supply chain. By using smart contracts and decentralized control, processes become more efficient and secure, with all lifecycle data captured from IoT sensors, RFID tags, and other sources. Independent supply chain blockchains communicate verified events via side chains, ensuring rapid validation and updating of digital product passports while significantly improving processing speed. The reference architecture shows how each component integrates to implement the DPP process through blockchain technology.

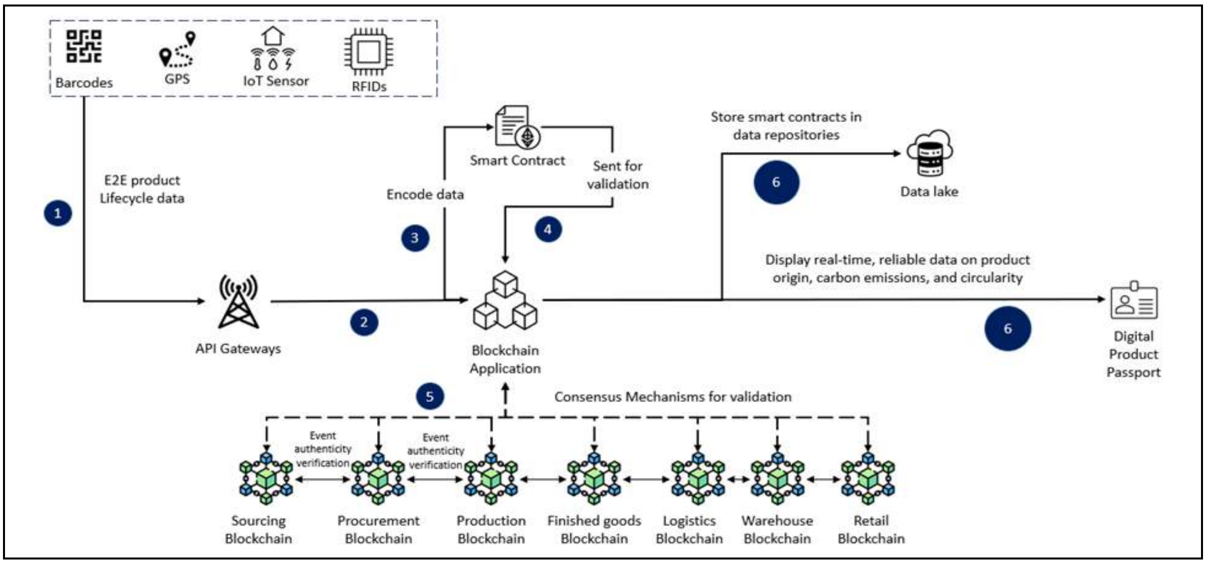

Figure 5 - Reference Architecture of enabling DPP through Blockchain

Implementation Framework: From Pilot to Scale

Organizations looking to operationalize blockchain-enabled traceability initiatives can consider a phased strategy that encompasses the following key stages:

Phase 1: Needs Identification and Technology Assessment
The first step involves pinpointing inefficiencies or value erosion within the existing supply chain ecosystem. For example, an initial gap analysis may reveal that 22% of active pharmaceutical ingredient shipments experience temperature deviations, a problem addressable via IoT-connected blockchain cold chain monitoring [10]. Additionally, conducting a digital maturity assessment for existing ERP systems is crucial, as legacy systems may not be ready for blockchain integration, often lacking the necessary infrastructure [7][8].

Phase 2: Pilot Program Design and Implementation
Designing and executing a limited-scale pilot program is critical for mitigating risks and quantifying potential returns on investment (ROI). Following are some best practices for this stage:

- Blockchain Consortium and Platforms: Joining forces with established blockchain consortia like the Linux Foundation’s Hyperledger Fabric can provide ready-made open source blockchain solutions. This approach has been shown to save 60–70% on development costs compared to in-house platforms [3][8].
- On-chain and Off-chain Hybrid Model: Consider implementing a hybrid data architecture that combines on-chain transactional data with off-chain databases for scalability and confidentiality. For instance, BMW’s PartsChain uses this approach for their over 3 million parts traceability requirements, with more than 80% of data stored off-chain [9].

Phase 3: Cross-ecosystem Collaboration and Incentivization
Achieving broad-scale ecosystem adoption requires strategic alignment and incentivization:

- Permissioned Visibility and Access Controls: Leverage smart contract capabilities to define varying degrees of visibility and data access, allowing upstream and downstream partners to see only the necessary aspects of a product’s lifecycle, while protecting sensitive business information [3][6].
- Digital Tokens and Economic Incentives: Develop and deploy blockchain-based digital tokens or assets, creating a value exchange between different ecosystem players. The Maritime Blockchain Consortium, for instance, provides digital tokens as an incentive for shipping companies to share real-time data on container locations. These tokens can be used to reduce port fees and charges, incentivizing the exchange of real-time information [7][8].

Phase 4: Deployment, Iteration and Scaling

Post-pilot validation, the initiative can be scaled up for wider deployment, guided by insights and successes from the pilot program. An example is Nestlé, which after a successful pilot phase, expanded their blockchain-enabled coffee traceability platform from 10 farms to over 50,000 farmers in 12 countries, resulting in an average of US $12/ton in savings on fair trade certification costs [8][10]. Emphasis should be placed on the following during this stage:

- Interoperability with Existing Standards: Ensure integration with prevalent standards, such as GS1’s digital link framework, which supports seamless integration with existing RFID tags and 2D barcodes [10][3]
- Regulatory Compliance: Proactively incorporate emerging compliance frameworks like the EU’s DPP requirements into the blockchain solution, enabling organizations to future-proof their sustainability data and reporting processes [7][8]
-

This blueprint offers a clear, scalable roadmap to help organizations implement blockchain-enabled traceability projects, addressing technical, compliance, and stakeholder needs.

Case Studies and Real-World Applications of Blockchain in CE

Blockchain technology has been implemented in certain use cases related to the CE. In these contexts, it has been applied to enhance transparency, traceability, and sustainability within global supply chains.

Case Study 1: Plastic Bank – Blockchain-Enabled Inclusive Circularity
Plastic Bank is a Vancouver-based social fintech company that has been building out a blockchain-enabled CE in plastic. Plastic Bank has identified vulnerable communities in Southeast Asia, Latin America, and Africa that it can work with to build sustainable local economies based on plastic waste collection. Plastic Bank's solution enables individuals to collect recyclable plastic and turn it into the company in exchange for tokens. These tokens can then be exchanged for a variety of goods and services needed by individuals in those communities [2]

Blockchain serves as a distributed ledger in the Plastic Bank ecosystem, tracking and verifying plastic collection and recycling activities. It ensures traceability of recycled materials back to their source, supporting sustainability claims for companies. This system incentivizes plastic collection with essentials like food, while also creating jobs and improving access to financial services, education, and healthcare for collectors.

Case Study 2: IBM Food Trust: Improving Traceability in Agri-Food Supply Chains
IBM Food Trust is a blockchain-based platform that aims to increase transparency, safety, and sustainability in the food supply chain. The solution provides end-to-end traceability by recording every transaction that a food product goes through from farm to table on an immutable ledger. Organizations across the agri-food supply chain, such as growers, processors, distributors, and retailers, can join the network and have controlled access to shared datasets.

Blockchain's immutable ledger speeds up identifying contaminated food, enabling targeted recalls that minimize health risks and waste. It also offers verifiable data on sourcing, environmental impact, and handling, supporting sustainable practices. Retailers can assure customers of ethical sourcing, and suppliers can demonstrate compliance with sustainability standards like organic or fair trade.

Future Outlook: The 2030 Supply Chain Ecosystem

By 2030, supply chains will operate as self-regulating, intelligent ecosystems based on blockchain, AI, and CE principles. Smart contracts will automate reordering, logistics, and dynamic pricing, with procurement cycle times shortened by up to 65% [4][9]. Digitally enforceable Product Passports will ensure fully traceable material flows through the supply chain and up to 92% of rare earth metals and other materials used in electronics will be reused at end of life, compared with <20% today [5][8].
Simultaneously, global ESG reporting standards will begin to harmonize, aided by new blockchain-enabled compliance tools. This is expected to save corporations US $180 billion per year in compliance costs and will lead to a new level of auditability and stakeholder trust [9][8].

Conclusion

Blockchain technology supports the circular economy by providing secure, traceable data for product design, tracking, and recovery in supply chains. It enables transparency through immutable records, smart contracts, and decentralized governance. DPPs facilitate compliance, consumer trust, and innovation for sustainability. With policies like the European Green Deal advancing, blockchain-based traceability will be vital for resilient, low-carbon, and transparent value networks. Future efforts should address implementation challenges and develop interoperable standards to scale these solutions. Blockchain-driven traceability offers a promising route to a more regenerative circular economy.

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* Reference adopted from Blockchain Council

Designing Low-carbon Innovation: Slowing Design Loops for Sustainable Resource Usage and Products

Idrees Rasouli

Associate Professor of Design and Urban Innovation

Cambridge School of Art,

Anglia Ruskin University

United Kingdom

Conference Topics:

- Design and Innovation Processes, Low-carbon Innovation, Tools and Methodologies

Conference Theme:

- Frameworks, Methodologies & Tools

Abstract

Global frameworks such as the Paris Agreement (2015) and the EU Circular Economy Action Plan (2020) highlight the urgent need for low-carbon innovation. Yet, mainstream design-driven innovation remains locked into consumerist logics, accelerating rapid product turnover and unsustainable outcomes. This paper introduces *Slowing Design Loops* (SDL) as a regenerative strategy that reorients innovation away from speed and disposability toward environmental stewardship and sustainability. SDL creates intentional, responsible, and careful innovations for low-carbon futures by combining Circular Economy, Systemic Design, and Responsible Innovation principles and is structured around four interlinked macro-intentions and micro-realities: *reaching backwards*, *shifting and rearranging emotion*, *reflexive and dialogical movement*, and *adjusting futures*. This study addresses: How can slowing design loops reorient innovation processes away from consumerist logics and towards regenerative, culturally grounded practices that foster stronger emotional connections to sustainability? A mixed-methods approach combining practice-based research, case studies, and practitioner interviews offers actionable pathways for advancing systemic, low-carbon futures.

Keywords: Slowing Design Loops, Low-carbon Innovation, Responsible Product Development, Systems Thinking, Regenerative Design Practices

Rethinking Innovation: Beyond Speed and Consumerism

Context and Motivation

Global frameworks such as the Paris Agreement in 2015 resulting from COP21 and the launch of the European Commission's Circular Economy Action Plan in 2020, have set a global mandate for low-carbon innovation, *urging systemic and intentional approaches* that shift innovation beyond linear, outcome-driven methods, in other words 'business as usual', towards regenerative pathways capable of mitigating climate change and resource depletion. These frameworks highlight the need to change our "*attitude towards innovation*" as a vehicle for "*constant growth and fast production to increase volume and reduce costs*" because "*it is not informed by a systematic approach*" (Gasparin et al., 2020). They underscore the need to rethink innovation not merely as a mechanism for generating new ideas or products for economic growth, but as a means of changing the way we design innovation and of shaping conditions, relationships, and cultural narratives that enable sustainable future. This rethinking must include a temporal reorientation that connects innovation to local heritage, resources, and community practices (Gasparin et al., 2020) by intentionally slowing the pace of design loops to create space for repair, adaptation, and cultural meaning-making within innovation processes.

Problem Statement

Existing circular economy strategies have primarily concentrated on technical measures such as resource efficiency, material longevity, and product durability (Bocken et al., 2016; de Sa and Korinek, 2021), yet these approaches often result in rapid product turnover, resource depletion, environmental harm, and socio-cultural consequences (Cowen, 2004). The original "slowing loops" concept introduced by Bocken et al. (2016) focuses on technical interventions through the design of long-life goods and product-life extensions. This slows the flow of resources by extending the use period of products but remains narrowly focused on technical lifecycles and materials flows. These measures build on earlier notions of "closing loops" (recycling and reuse) and "narrowing loops" (lightweighting, reducing materials input per product) (Bocken et al., 2018).

While all these three approaches are essential, they often overlook the spatial, temporal, and cultural dimensions that design is uniquely positioned to address (Ellen MacArthur Foundation, 2022; Rasouli, 2025a), which is the focus of this paper (Figure 1). Transitioning to decarbonised and carbon-negative futures by 2050 is not solely a technical challenge but also a creative and social one that demands deliberate, systemic thinking to navigate interconnectedness, interdependencies, and uncertainties of innovation processes (Design Council, 2021). It requires design to reimagine not just products but the conditions, relationships, and cultural narratives that shape innovation itself (Nelson, and Stolterman, 2012).

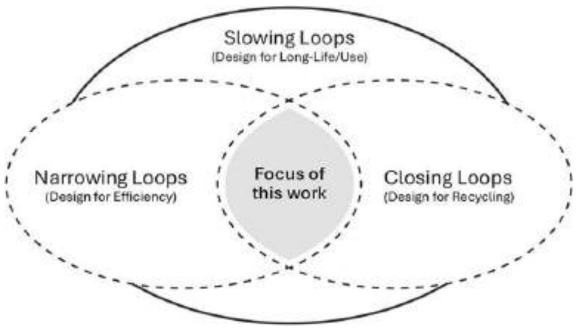

Figure 1. Thematic Arrangement of the present work in the intersecting field of Slowing Loops (by Author based on Bocken et al., 2016)

As one of the oldest traditions of human inquiry and action, design enables us to imagine and shape new conditions and systems, directing attention toward areas most in need of care and creativity (Nelson, and Stolterman, 2012). Recent reflections, such as those presented in the short film *Towards a Dynamic Discipline of Design* (Vlahos, 2025), emphasise that design is not static and must evolve in response to shifting societal, environmental, and cultural conditions. In this context, design has the potential to slow down the pace of production and consumption, reorienting innovation away from speed, human-centricity, and disposability, and toward a more attentive, situated, and transformative practice (Rasouli, 2025b).

Ye weaknesses persist in design's academic (Pineda et al., 2024) and business (Baldassarre, 2020) frameworks, limiting their ability to enable inclusive transitions toward sustainable modes of development, production, and consumption. Today's hasty material culture and modern need for convenience have meant that we often "*design products to suit*" rather than taking "*enlightened design decisions*" (Micklethwaite, 2019). These gaps also constrain innovation, as current design-driven approaches often reinforce linear, speed-driven paradigms for new product development that focus on meeting existing needs and creating new forms of consumerism through the transformation of meaning, rather than fostering regenerative approaches adaptable to changing business and cultural contexts (Secomandi, 2024). As a result, design-driven innovation tends to prioritise market impact and symbolic value over systemic sustainability or cultural grounding (Gasparin, 2020), leaving opportunities to slow and contextualise design loops underexplored.

Several frameworks have attempted to respond to this need. Hernandez and Goñi's (2020) *Responsible Design for Sustainable Innovation* was one of the first ones to systematically address the shortcomings of conventional design-driven innovation models. It extended the Design Council's widely used Double Diamond model, which argued that responsibility and sustainability must be embedded across the innovation process through principles like avoiding harm, enhancing social and environmental value, and fostering inclusive participation. However, their findings show that many organisations still adopt responsibility late in the innovation process, often as compliance or reputational measures, thus limiting its potential to shift innovation systems at a deeper cultural, temporal, or geographic level (Hernandez and Goñi, 2020). Figure 2 summarises their responsible design framework, which offers practical guidance for integrating responsibility but remains primarily oriented toward process efficiency.

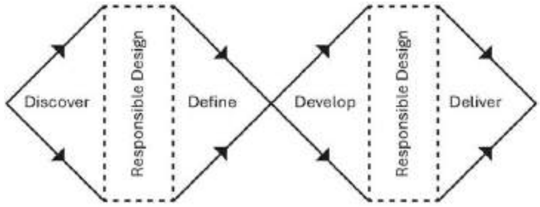

Figure 2. Responsible Design for Sustainable Innovation (Hernandez & Goñi, 2020)

Similarly, the Design Council's *Beyond Net Zero: A Systemic Design Approach* revisits and evolves the Double Diamond to address climate and systemic challenges, acknowledging that earlier versions were too linear and insufficiently attuned to systemic design. It emphasises reframing, leadership, and collaboration as essential for regenerative innovation by expanding the model to include new phases for catalysing, convening, and embedding change (Design Council, 2021). Figure 3 illustrates this updated framework, which represents a significant step forward, however it still maintains a pace-driven, outcome-oriented logic that does not explicitly encourage slowing design loops or grounding them in geographic, social, and ecological realities. Its focus remains on enabling innovation to scale and accelerate impact (Gasparin et al., 2020), which risks reinforcing linear, speed-driven paradigms rather than challenging them.

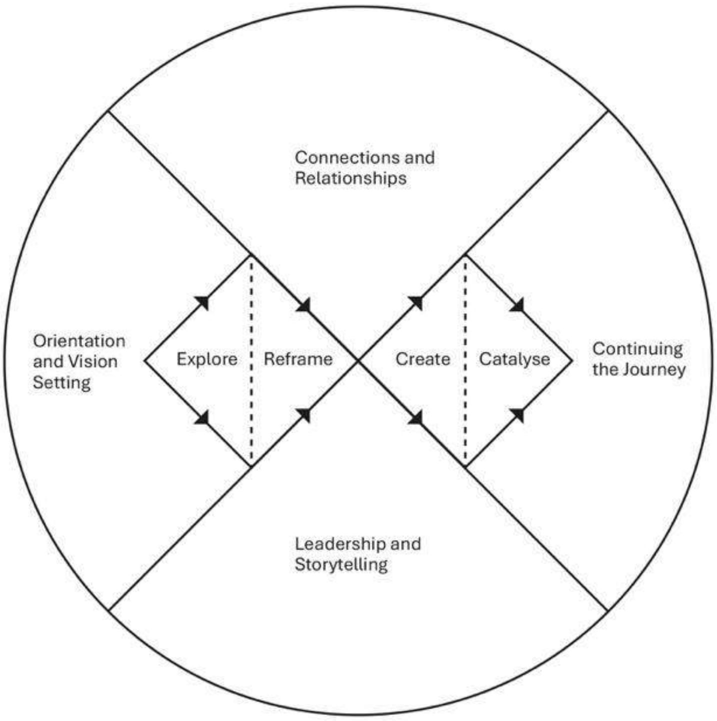

Figure 3. Beyond Net Zero: A Systemic Design Approach (Design Council, 2021)

As a result, both frameworks advance responsible and systemic thinking but stop short of reconfiguring innovation processes to allow for contextual reinterpretation, slower temporality, and the cultivation of emotional and cultural narratives. They fall short in enabling innovation that is adaptive, culturally grounded, and capable of fostering deeper emotional and systemic connections between people, products, and planetary boundaries (Voulvoulis et al., 2022). Despite advances in circular economy, systemic design, and responsible innovation, existing frameworks remain largely speed- and efficiency-oriented. They privilege technical solutions (e.g., material efficiency, product durability) while overlooking the temporal, cultural, and emotional dimensions that shape innovation process and outcomes.

This gap is further amplified by the rise of AI-driven personalisation, predictive purchasing, and behavioural nudging (Government Digital Service, 2025), which accelerate consumption cycles and risk reinforcing bias and manipulation. Together, these factors underscore the urgent need for a framework that makes time, care, and cultural grounding central to innovation, while also offering practical tools for operationalising slowness in design processes.

Expanding the role of innovation beyond creating new ideas and artefacts toward designing conditions and regenerative systems requires storytelling and narratives that challenge dominant ideologies of consumerism, entrepreneurialism, and growth drivers of high-carbon, extractive economies (Huber, 2013). Alternative strategies, such as distributed design or designing under extreme resource constraints, highlight how slowing and contextualising design can help innovation more adaptive, systemic, and culturally grounded by providing it with a richer method for addressing complex sustainability challenges while fostering deeper human-environment-ecology connections (Rasouli, 2025a).

Slowing Design Loops (SDL) is introduced in the following section as such a framework. SDL directly responds to the gaps identified above, equipping designers, innovators, and policymakers with *intentional* (Plattner et al., 2014), *responsible* (Kiran, 2012), and *careful* (Helms, 2020) practices that align cultural, situational, and ecological priorities. It fosters slower, more meaningful innovation that advances low-carbon, regenerative futures by making time, space, and care active design materials rather than passive constraints.

Research Questions

Building on these gaps, this study asks: *How can slowing design loops reorient innovation processes away from consumerist logics and towards regenerative, culturally grounded practices that foster stronger emotional connections to sustainability?* By exploring how slowing design loops can reshape innovation, this study seeks to uncover pathways for embedding temporal, cultural, and emotional depth into the innovation process. Such an approach allows for regenerative practices that are context-sensitive, enabling design to respond to diverse geographic, social, and ecological realities rather than applying universalised, growth-driven methods (Buckton et al., 2023). Moreover, investigating how slowing design loops can cultivate narratives that emotionally engage users offers a way to shift collective mindsets from consumption to stewardship, fostering longer-lasting relationships between people, products, and planetary systems. The findings aim to provide designers, innovators, and policymakers with actionable strategies to embed low-carbon futures within both design practice and socio-cultural systems (Chen et al, 2022).

Slowing Design Loops: Concept and Contribution

According to Innovate UK (United Kingdom's innovation agency) "*effective innovation includes design activities to create solutions that are better, more desirable and fit-for-purpose*", emphasising that design, in the context of innovation, "*brings an approach or methodology that puts people at the heart of innovation process, delivering greater value by making sure that the outputs are desirable and fit-for-purpose*" (Design in Innovation Strategy 2020-2024). This human-centred perspective, which is commonly associated with 'design thinking' (Brown, 2008; Kelley, 2004), is also reflected in global sustainability policy, which often frames design primarily as a tool for technological innovation and behaviour-change initiatives aimed at influencing individual consumer choices within existing systems of production and consumption (Welch, and Southerton, 2019). Design thinking's emphasis on empathy, integrative thinking, optimism, experimentalism and collaboration has undoubtedly enhanced problem-solving capacity and driven efficiency and market responsiveness. However, by centring innovation on rapidly meeting human needs, it has also reinforced an individualised understanding of responsibility for climate action and contributed to unsustainable product lifecycles. This human-centred focus often accelerates the creation of short-lived action rather than longer-term ambitions, increases resource use, and normalises disposaibility (Welch, and Southerton, 2019) once the need or problem is perceived as solved—perpetuating cycles of consumption rather than addressing their root causes.

This framing positions the burden of tackling climate change onto end-user decision-making, diverting attention from the deeper social practices, institutional structures, and innovation processes that shape unsustainable outcomes (Harvard Politics, 2020). As Bocken et al. (2016) warn, efficiency-focused circular strategies risk creating 'rebound effects,' where gains in resource efficiency actually accelerate consumption rather than reduce it. Gasparin et al. (2020) similarly argue that the dominant "*attitude towards innovation*" ties it too closely to economic growth, fast production, and volume maximisation. Consequently, design is frequently positioned as an enabler of "*responsible*" consumption in the innovation process rather than as a driver of systemic transformation, risking the reproduction of the very consumption patterns it aims to disrupt (European Environment Agency, 2017). Conventional design-driven innovation approach further reinforces this limitation by prioritising novelty, speed, efficiency, and progress in the form of symbolic differentiation, while neglecting the histories of displacement and harm they leave behind (Parater, 2021). They perpetuate extraction and destruction by creating *meaning* primarily for markets while being complicit in "*defuturing*" (Fry, 2014) rather than empowering designers, innovators, and policymakers to practice intentionality, responsibility, and care. This contrasts with what Roberto Verganti (2009) describes as "*design discourse*"—an explicit and implicit research-driven, dialogical process of listening, interpreting, and co-creating new visions that are both culturally and systematically grounded (Kristiansen, 2018).

Slowing Design Loops (SDL) is introduced in this paper as a *regenerative strategy* (Figure 4) designed to counteract the acceleration logic embedded in contemporary innovation processes. Rather than following linear, speed-oriented trajectories, SDL broadens the scope of design practice to embrace a dynamic, fluid, and dialogic approach that foregrounds reflection, cultural grounding, and systemic thinking. This orientation mirrors the evolving nature of design as a discipline, characterised by its inherent *adaptability* to non-linear careers and practices (Bethune, 2025), its *alterplinarity* that allows collaboration across and beyond disciplinary boundaries (Rodgers, and Bremner, 2016), and its *intelligibility* that enables us to purposefully diverge and converge diverse perspectives, knowledge systems, and ideas to remain responsive to complex planetary and societal challenges (Ottino & Mau, 2022).

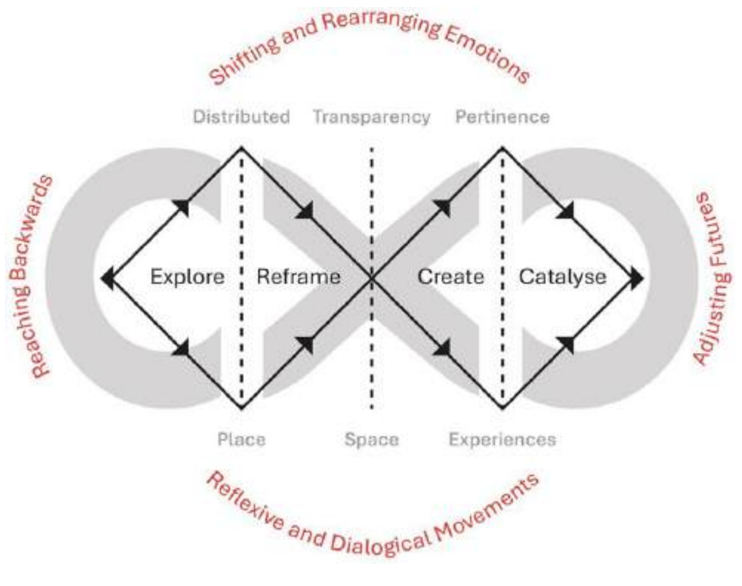

Figure 4. Slowing Design Loops: A Regenerative Design Approach (by Author based on Hernandez & Goñi, 2020 and Design Council, 2021)

SDL is thus defined as a deliberate reorientation of innovation away from novelty, speed, efficiency, and progress toward temporal depth, cultural grounding, and environmental stewardship. It treats time and space not as constraints but as active design materials—stretching and shaping activities and behaviours to allow for reflection, repair, and contextual adaptation. This temporal and spatial attentiveness fosters deeper creative thinking and higher performance (Lee, and Lee, 2023), while embedding social and ecological objectives as core design drivers rather than peripheral add-ons (Hernandez and Goñi, 2020).

Central to SDL is its organisation around *macro-intentions* and *micro-realities*, which together create a bridge between high-level aspirations and day-to-day design practice. Micro-intentions are the deliberate, strategic aims that shape the direction of innovation, described by Muller and van Tulder (2021) as "*systemic intentions*" that capture the cultural, temporal, and ecological aspirations that SDL seeks to advance through slowing decision-making, embedding care, and aligning with planetary boundaries. In contract, micro-realities represent the spatial and ecological practices, behaviours, and activities through which these intentions are enacted, or sometimes resisted, in everyday innovation processes. Merleau-Ponty (2012) describes these as "*cues*" that contribute to the dynamic, lived experience of innovating, highlighting the importance of embodied, sensory interactions in the innovation process.

Conceptually, SDL synthesises three complimentary bodies of knowledge: Circular Economy principles, which focus on resource longevity, repair, and regenerative flows (Ellen MacArthur Foundation, 2022); Systemic Design, which focuses on relationships, interdependencies, and co-creation (Jones, 2014); and Responsible Innovation, which prioritises anticipation, reflexivity, and alignment with collective societal values (Stilgoe, 2013; Kiran, 2012). Together, these foundations position SDL as a framework for slowing innovation loops in ways that are simultaneously practical, systemic, and culturally meaningful. In doing so, SDL fills a critical gap in existing frameworks by foregrounding time, meaning, and care as central elements of innovation—dimensions that are often overlooked in speed- and growth-driven approaches. Treating *time* as a design material encourages slowing down decision-making cycles to surface latent needs, unintended consequences, and opportunities for repair before scaling solutions (Russell et al., 2023). Its emphasis on *meaning* situates innovation within specific cultural and geographic contexts, enabling design to move beyond universalised, market-enteric outcomes toward locally resonant and socially embedded interventions (Santamaria et al., 2017). The focus on *care* reframes innovation as an ongoing commitment to people, places, and planetary health through ethically informed practices and emotional awareness (Moriggi et al., 2020).

Together, these shifts enable researchers and practitioners to link how geographic and socio-political pressures shape macro level societal outcomes, such as resource scarcity, climate inequities, and systemic exclusion, while also capturing micro level impacts across organisational processes, material flows, and user behaviours (Harris, et al., 2021). In this way, SDL offers both a conceptual and operational bridge between the strategic and situated dimensions of innovation, equipping designers, innovators, and policymakers to generate low-carbon, culturally meaningful, and context-sensitive futures.

As illustrated in Figure 4, there are four interlined macro-intensions at the core of SDL, each offering a pathway to slow down and deepen innovation processes. *Reaching Backwards* calls for engaging with historical, cultural, and local knowledge to inform new ideas and solutions before converging on solutions, creating continuity with past and existing practices rather than erasing or disregarding them (Terry et al., 2024). This initial stage in the innovation process emphasises a decolonial approach where envisioning the future has deep roots in the past and necessitates considering a multiplicity of pasts. The next stage, *Shifting and Rearranging Emotion* focuses on reconfiguring the emotional drivers (inherent in our ideas, expectations, and habits) that shape innovation, guiding design away from a focus on novelty-seeking toward ecological stewardship, ethical attachment to its purpose, and the creation of long-term value (Sörgel, 2024). This is followed by, or can occur simultaneously with, *Reflexive and Dialogical Movement*, which emphasises continuous reflection and stakeholder dialogue to navigate and address complex problems, while resisting premature convergence and allowing for emergent outcomes (Sherman et al., 2023). Finally, *Adjusting Futures* broadens the range of possible futures considered in the innovation process, unstitching errors accumulated from the rapid pace of technology and enabling multiple, slower pathways to innovation, aligning closely with the concept of 'anticipatory innovation governance' (Tõnurist and Hanson, 2020), which emphasises shaping and preparing for uncertain futures rather than pursuing a single, fast solution.

Together, these four dimensions foster intentional, responsible, and careful design practices that align cultural, situational, and ecological priorities, contributing to systemic, regenerative, and low-carbon futures, and positioning SDL not just as a theoretical framework but as a practical, regenerative lens for rethinking how innovation in organised and developed. The following section presents the methodology, explaining how the concept was formulated and implemented through practical tools and approaches.

Methodology: Exploring SDL in Practice

Building on the SDL conceptual framework, this study was conducted in two phases: 2019-2022 (in Istanbul, Türkiye and Kabul, Afghanistan) and 2023-2024 (in Cambridge, United Kingdom). A mixed-methods, practice-based approach was adopted to explore SDL as both a conceptual lens and a practical tool for fostering low-carbon, regenerative innovation. This approach incorporates qualities inspired by regenerative thinking—an ecological worldview that is embodied in human action and sustained through continuous reflexivity (Buckton et al., 2023). It emphasises temporal depth, cultural grounding, and systemic thinking, linking macro-level aspirations with micro-level design practices.

The participants for this study were deliberately chosen using purposive sampling as a "*deliberate process of selecting participants who share specific qualities that are relevant and have the potential to answer the inquiry*" (Creswell and Poth, 2017). One designer/makers from a pool of 21 were chosen in Istanbul and one from a pool of 72 in Kabul. The small sample size was selected to allow for deep, longitudinal engagement through extended observation of design practices over time and detailed examination of participant engagement (Ochieng et al., 2021). To ensure alignment with SDL principles, participants were selected for their engagement with local materials, cultural practices, and systemic design approaches (Figure 5), which is a key characteristic of practice-based methodology. Ethical approval was obtained, and participants provided informed consent in return for a small cultural gift.

Alignment with SDL Principles	Istanbul, Türkiye		Kabul, Afghanistan	
	Invited	Interviewed	Invited	Interviewed
Engagement with Local Materials	9	4	29	6
Engagement with Cultural Practices	7	3	34	8
Engagement with Systemic Design Approaches	5	3	9	3

Figure 5. Participants' Recruitment and Alignment based on SDL Principles

To operationalise this approach, SDL's four macro-intentions (Reaching Backwards, Shifting and Rearranging Emotion, Reflexive and Dialogical Movement, and Adjusting Futures) served as guiding principles throughout the research process. These macro-intentions provided a structured lens for exploring the central research question: *How can slowing design loops reorient innovation processes away from consumerist logics and towards regenerative, culturally grounded practices that foster stronger emotional connections to sustainability?* They enabled the research to interrogate the historical, cultural, and emotional dimensions of innovation practices and to cultivate temporal depth within design and decision-making cycles.

- **Reaching Backwards** was explored primarily through *distributed design case studies*, where participants acted as reflective practitioners (Frayling, 1993), demonstrating how they engaged with local histories, cultural narratives, and traditional material practices to inform their innovation strategies. These cases were analysed for processes, decision-making logics, and moments of "slowing" and "reorientation" within innovation loops (Bocken et al., 2016; Yin, 2018).
- **Reflexive and Dialogical Movement** was embedded throughout the *practice-based research component*, using iterative prototyping and stakeholder dialogues to slow convergence, surface hidden assumptions, and co-create alternative trajectories for innovation (Sherman et al., 2023). This phase involved tracing design influences, resource flows, and community-based collaborative practices to create room for "strategic slowness" - slowing decision-making cycles, surfacing latent needs and unintended consequences before converging on new ideas or solutions (Dunn, 2025).
- **Shifting and Rearranging Emotion** was investigated afterwards through *semi-structured practitioner interviews* with designer/maker participants, who reflected on how cultural drivers, emotional dynamics, and systemic barriers shape decision-making, and how they might be reconfigured to foster longer-term stewardship and ecological responsibility (Santamaria et al., 2017). These conversations complemented the observational case study data (Braun and Clarke, 2006).
- **Adjusting Futures** guided a future-oriented analysis, using a second round of *semi-structured practitioner interviews* to 'take a step back from the evidence' (Feyerabend, 2010) and analyse the outcomes from the previous phases, understanding what alternative approaches could be considered as future-oriented analysis (Fauré et al., 2017). This final step emphasised the

importance of multiple, slower temporalities rather than linear, accelerated trajectories (Tõnurist and Hanson, 2020).

In parallel, micro-realities were documented through *thematic coding* (Braun and Clarke, 2006) and *pattern tracing* (Yin, 2018), while reflexive journaling was used to capture the spatial, cultural, and ecological practices through which these macro-intentions were enacted on the ground. These included the observation of organisational routines, material flows, and community-level dynamics, as well as moments of resistance or friction where intentions encountered systemic constraints. This triangulation of methods (combining practice-based research, case studies, and interviews) produced an integrated, multi-perspectival account of slowing design loops (Candy & Edmonds, 2018).

Operationalising SDL: Tools and Approaches

SDL's strength lies in its ability to move conceptual principles to actionable practices through localised, culturally resonant methods and equipment that are affordable and accessible to everyone, suitable for emerging small to medium scale enterprises, and compatible with our needs and creativity (Schumacher, 1973). Practicing SDL relied on three interdependent tools and approaches place-based design, narrative prototyping, and system mapping each contributing to temporal depth, cultural grounding, and emotional resonance in innovation when designing *ince belli* in Istanbul and *hawa* in Kabul (Figure 6).

Figure 6. Ince Belli tea glass saucer by Artin (Istanbul, left) and Hawa household food dehydrator by Nizrab (Kabul, right)

Place-based Design: Drawing on Escobar's (2018) notion of "designs for the pluriverse", place-based design was used to foreground the relationship between innovation and its materials, historical and cultural context. It helped with *resisting the universalising of tendencies* by allowing to situate the innovation processes within local ecologies, infrastructures, and knowledge systems (Ortiz et al., 2025).

In Istanbul, this meant repurposing this meant *repurposing* metal sheet pieces (Figure 7, left) and revisiting the cultural history of the Turkish *ince belli* tea glass and saucer. This process combined Schon's (1991) "reflective practitioner" approach with Foucault's (1988) notion of self-disciplining practice, requiring ongoing self-critique and iteration. In Kabul, place-based design was expressed through the *reuse* of discarded fan blades (Figure 7, right), heat exchangers, and local scrap metal, which were adapted and reconfigured to create a culturally relevant household food dehydrator. Both cases demonstrate that place-based design is a reflexive, dialogical process that goes beyond merely engaging with and using local materials to also activate temporal depth. This approach enabled to trace influences and resource flows by *reaching back* to past artefacts, tools, and rituals in order to shape present and future forms of life (Mignolo and Walsh, 2018).

Figure 7. Repurposing metal sheet pieces (Istanbul, left) and Reuse of discarded fan blades (Kabul, right)

Narrative Prototyping: Building on Dunne and Raby's (2013) design fiction and speculative design, narrative prototyping was used to help *embed design prototypes within cultural and emotional narratives*, such as lived experiences of diverse people representing the end-users. This approach enabled co-creating meaning-making by *challenging and redefining the meaning of circumstances and reappropriate emotions* that came along with them (Hilmar et al., 2024). As a tool, it allowed to *slow premature convergence* by testing not only functional performance of the innovation but also cultural and symbolic resonance (Laine et al., 2025), considering factors such as emotional attachment and durability (Chapman, 2005).

In Istanbul, narrative prototyping involved *storying the tea ritual* (Figure 8, left) to embed the innovation in historical and social narratives that allowed end-users to evaluate whether it preserved the cultural continuity of tea drinking. In Kabul, narrative prototyping mean *relinking to the deep tradition of food preservation* (Figure 8, right) while reimagining it for an urban, resource-constrained context. In both cases, the prototypes served as prompts for shared reflection and negotiation between familiar and imagined cultural practices. This approach enabled the shifting and *rearranging of emotions* by framing experimentation as a site of collective epistemic discovery (Rheinberger, 1997).

Figure 8. Storying the tea ritual (Istanbul, left) and Relinking to the deep tradition of food preservation (Kabul, right)

System Mapping: To operationalise the systemic design dimension of SDL, system mapping was employed to visualise feedback loops, dependencies, and leverage points (Meadows, 2008; Jone, 2014). This tool helped identify where to 'slow' loops collectively whether material, cultural, or behavioural for maximum impact.

In Istanbul, system mapping clarified the *lifecycle of the tea saucer* (Figure 9, left), from sourcing to repair and reuse, uncovering points of cultural vulnerability such as the risk of replacing traditional saucers with cheap imports, which, according to the participants, have prohibited innovation opportunities within the household sector. In Kabul, mapping involved *tracing the seasonal cycles of food security, availability of energy, and user interaction and need patterns* (Figure 9, right), ensuring that the innovation would remain viable in off-grid conditions. System mapping thus functioned as a systemic design lens for *adjusting futures*, aligning each intervention with both ecological and cultural systems ensuring they were not isolated artefacts but sustainable nodes in a living, temporal network, shaping future practices, uses, and relationships (Design Council, 2021).

Figure 9. Clarifying the lifecycle of the tea saucer (Istanbul, left) and Tracing the seasonal lifecycles and need patterns (Kabul, right)

Visualising SDL and Its Implications for Practitioners

Based on these findings, Figure 10 visualises how SDL's four micro-intentions (Reaching Backwards, Shifting and Rearranging Emotion, Reflexive and Dialogical Movement, Adjusting Futures) align with dimensions of innovation practice (local materials, cultural practices, systemic approaches) and temporal depth. Operationalising SDL provides practitioners with a structured, actionable framework to embed slowness and cultural resonance into their innovation processes (Rasouli, 2025a).

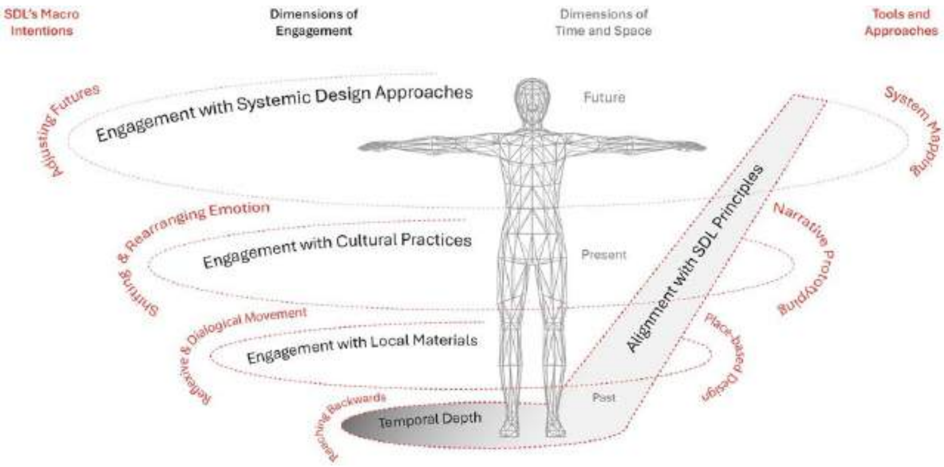

Figure 10. Visualising SDL: Connecting Macro-Intentions with Engagement Dimensions and Operational Tools

SDL's three tools (place-based design, narrative prototyping, and system mapping) move designers from abstract principles to situated action. Place-based design enables practitioners to work with local materials, histories, and ecologies, fostering innovation that honours continuity and repair (Escobar, 2018). Narrative prototyping invites communities into the process, testing not just functional performance but also cultural meaning and emotional durability (Chapman, 2005). System mapping surfaces leverage points where slowing can create the most systemic impact, aligning product lifecycles with planetary boundaries (Meadows, 2008). Together, these tools help practitioners resist default speed-driven, universalised approaches and create solutions that are contextually grounded, regenerative, and socially embedded (Design Council, 2021). This positions practitioners as stewards of meaningful value, while connects innovation to long-term cultural and ecological continuity (Mang and Haggard, 2016).

Findings: SDL Impacts on Innovation and Culture

Findings from participant interviews highlighted that practicing SDL "*slowed unnecessary iterations*," which in turn reduced designed outputs and the possibilities of overproduction. Slowing design loops helped with creating "*breathing rooms*" for deeper storytelling and emotional connection with the materials and resources at hand, allowing innovation to transcend functionality and enter the realm of cultural practice, fostering durable, low-carbon relationships between people, products, and places (Tonkinwise, 2015).

Reducing Consumerist Dependency

Participants shared that "*designing more consciously and thoughtfully*" allowed them to align with calls for degrowth-oriented innovation strategies (Schneider et al., 2010). By reviewing energy costs and measuring the use of both raw and reused materials, the findings showed 35-40% reduction in energy use and a 20-25% reduction in material consumption compared to similar projects of comparable size and complexity by the participants. These results demonstrated that SDL could mitigate rebound effects (Bocken et al., 2016).

Strengthening Emotional Connections

Further findings from participant interviews revealed that slowing design loops facilitated "*collaborative reflection across distributed teams*" who use and share tools and equipment. This process created space for shared systemic understanding, shaped by a series of links between the sense of social immediacy, the available technologies, and the relativity of the locality (Appadurai, 2018). Additionally, participants' narratives around reusing materials and responsible practices in the design of advanced home appliances provided cultural resonance, fostering a sense of pride and ownership among potential end-users, a behaviour associated with emotional durability (Chapman, 2005).

Systemic and Cultural Impacts

Slowing design loops facilitated collaborative reflection, creating space for shared systemic understanding of the limitations inherent in conventional innovation methods. A key finding from the interviews was that stakeholders demonstrated a greater willingness to challenge growth-driven approaches and instead adopt more holistic ones that integrate environmental, cultural, and social indicators. This shift initiated a rethinking of existing studio and workshop cultures in both Istanbul and Kabul, enabling meaningful discussions on how best to embed sustainability into long-term practices of thinking and making, rather than treating it as a siloed area of expertise (Iacovidou et al., 2020).

Broader Lessons

The findings from this study highlight several transferable insights. First, *temporal stretching* (the intentional use of structured pauses) proved valuable for identifying systemic risks and unintended consequences prior to developing and scaling interventions. Second, *narrative integration* emerged as a powerful mechanism for deepening user engagement, fostering a sense of stewardship and shared responsibility. Third, *systemic awareness* (achieved through mapping networks and feedback loops) helped locate high-leverage points for intervention and facilitated more strategic decision-making. These lessons are particularly applicable in sectors with high turnover rates, such as household products, apparel, and construction, where slowing design loops can simultaneously reduce carbon impacts and reinforce cultural identity through more durable, meaningful forms of designing, producing, and consuming.

Discussion: SDL as a Pathway to Low-carbon Futures

SDL reframes *innovation as a space for care, reflection, and regeneration*, aligning closely with the EU Circular Economy Action Plan (European Commission, 2020). By embedding storytelling and place-based engagement, this study has shown that SDL fosters collective responsibility and transforms sustainability from a compliance exercise into a cultural, relational, and spatial practice. Thus, SDL can contribute to long-term resilience by ensuring that products and systems evolve with ecological limits rather against them (Iyer et al., 2021).

Challenges

Considering that corporate businesses will continue to prioritise speed-to-market and profitability, slowing design loops can be perceived as inefficient or costly (Geissdoerfer et al., 2018). A key challenge emerging from this study is that cultural adoption of SDL requires time, facilitation, and engagement at every part of the value chain. which may conflict with short-term stakeholder, especially investor, expectations. Potential measures can include rewarding longevity, repairing, and community impact, alongside policy incentives that encourage caring and responsible business models capable of balancing economic performance with long-term social and ecological value (European Parliament, 2023).

Opportunities, and Implications

As this study has shown, SDL has potential for cross-sector scaling. Businesses can use it to build brand trust through authenticity and durability. On the other hand, educators can embed SDL into curricula, training future designers in caring, reflective, and regenerative practices, while policymakers can create enabling conditions and social and physical infrastructures. These opportunities collectively position SDL as a crucial pathway toward achieving net-zero and regenerative futures.

Conclusion: Designing Intentional, Responsible, and Careful Innovation

Slowing Design Loops reframes innovation as a deliberate act of resistance against the relentless acceleration of production and consumption (Parater, 2021). It challenges the prevailing assumption that faster is always better, positioning time and space not as a constraint but as a vital material that enables reflection, repair, and cultural continuity. Rather than driving growth through rapid turnover, SDL nurtures low-carbon futures by creating space for systemic awareness, emotional engagement, and locally resonant solutions that align with planetary limits.

Actionable Recommendations

This study demonstrates that slowing loops is not inefficiency but a form of strategic intelligence that replaces “prevailing linear model of production and consumption systems with regenerative cycles that prioritise resource efficiency, waste reduction, and environmental sustainability” (Munonye, 2025). By situating innovation within place-based contexts, embedding cultural narratives, and integrating systemic thinking, SDL transforms sustainability from a compliance exercise into a shared cultural project aligned with long-term ecological and social goals.

Future Research

Looking forward, the promise of SDL lies in its potential to reshape entire industries, education systems, and policy frameworks. Future research should test SDL at scale, investigate its intersections with emerging technologies, and track its capacity to decouple innovation from extractive growth. As the *Townscapes* report reminds us, innovation must “*ensure that the benefits of innovation are widely shared*” through coordinated, inclusive strategies across regions and communities (Coyle and Selvi, 2024). In doing so, SDL offers a radical yet practical pathway toward a post-growth economy (Hofferberth, 2025) one where innovation becomes a means of inclusive growth, care, repair, continuity, and collective flourishing.

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Integrating Circular Economy Principles into New Product Development: Challenges and Opportunities in the Household Appliance Sector

Benedetta Rotondo
PhD student
Department of Design
Politecnico di Milano
Italy

Venanzio Arquilla
Associate Professor
Department of Design
Politecnico di Milano
Italy

Abstract

The household appliance sector faces growing pressure to reduce its environmental footprint, due to intensive resource consumption and the rapid increase in electrical and electronic waste (e-waste). Regulatory frameworks such as the Circular Economy Action Plan (CEAP) and the Ecodesign for Sustainable Products Regulation (ESPR) are pushing manufacturers toward more sustainable and circular innovation models. However, the integration of Circular Economy (CE) principles into New Product Development (NPD) processes remains fragmented and underexplored. This study presents a systematic literature review, conducted following the PRISMA protocol, to investigate how circular strategies, tools, and practices are currently adopted in NPD, with a specific focus on the household appliance sector. The analysis highlights key opportunities for embedding circularity at the early stages of product development, especially within the fuzzy front-end, and emphasises the crucial role of designers as facilitators of cross-functional collaboration. The study identifies major enablers such as leadership commitment and interdisciplinary competencies, alongside persistent barriers including organisational silos, technical knowledge gaps, and cost-related challenges. The findings provide strategic insights for companies aiming to embed circular principles into NPD and call for further research into actionable implementation frameworks tailored to the sector's specific needs.

Keywords: Circular Economy, New Product Development, Sustainable Innovation

Introduction

The household appliance sector significantly contributes to environmental degradation, due to its intensive use of finite raw materials, high energy consumption, and the generation of increasing volumes of electrical and electronic waste (APPLiA Italia, 2018; Eurostat, 2024). According to the European Commission, less than 40% of e-waste is currently recycled, with most products incinerated or landfilled, leading to the loss of valuable resources, increased carbon emissions, and serious health risks (European Commission, 2023b; European Parliament, 2024). As environmental awareness among consumers rises and corporate social responsibility gains importance, companies face growing pressure to adopt more sustainable innovation models (Bressanelli *et al.*, 2020).

Regulatory frameworks such as the Circular Economy Action Plan (CEAP) and the new Ecodesign for Sustainable Products Regulation (ESPR), which entered into force in July 2024, promote the transition from the traditional linear model (characterised by the “take-make-use-dispose” pattern) to circular systems where materials and components are maintained in use for as long as possible to minimise waste and create new values (European Commission, 2023a; Ellen MacArthur Foundation, 2024). These policies push companies to rethink how they design, develop, and deliver their products.

In this context, the New Product Development (NPD) process plays a pivotal role in enabling the shift toward circular economy (CE) models. While NPD is a strategic innovation driver, recent research shows that the integration of circular principles within it remains limited and fragmented (Bressanelli *et al.*, 2020). In particular, although circular business models have gained increasing attention, the operational tools and methods to support circularity in the design and development phases are still underexplored (Hashiba and Paiva, 2016; Nyström *et al.*, 2021; Aguiar and Jugend, 2022).

This paper addresses this gap through a systematic literature review following the PRISMA protocol (Page *et al.*, 2021), focusing on the intersection between NPD and CE. The objective is to classify existing circular practices, identify key enablers and barriers, and derive implications for companies pursuing sustainable innovation. Previous critical literature reviews have explored the integration of sustainability into the product development process (Sihvonen and Partanen, 2016; Pinheiro *et al.*, 2019). Building on these, the present study addresses the following research questions:

RQ: “What are the emerging circular economy practices and the related opportunities and limitations for their implementation in the NPD process?”

The paper aims to trace the evolution of these concepts in the literature and explore their potential integration, with a specific focus on manufacturing companies and their business innovation, particularly in the household appliance sector.

The next sections are organised as follows: Section 2 provides the theoretical background on the terms NPD and CE in the context of business innovation. Section 3 outlines the research methodology adopted. Section 4 presents the results of the systematic review. Section 5 provides a discussion, and finally, Section 6 offers the research conclusions.

Theoretical Background

The New Product Development (NPD) process is a structured sequence of activities aimed at transforming ideas into marketable and differentiated products that respond to technological advancements and customer needs (Cooper and Edgett, 2008; Kahn, 2018). Core elements include cross-functional collaboration, strategic planning, and iterative decision-making (Genç and Di Benedetto, 2015).

A well-structured NPD process supports project control, improves efficiency, and mitigates risks (Owens and Cooper, 2001). It has become a crucial driver of innovation and competitiveness in dynamic markets (Smolnik and Bergmann, 2020; Iqbal and Suzianti, 2021). NPD draws upon a range of organisational resources, such as human capabilities, technical expertise, customer insight, and infrastructure (Peng, Wang and Jiang, 2008; Helfat and Peteraf, 2009; Wu, Melnyk and Flynn, 2010). To be effective, it also relies on dynamic capabilities and enabling institutional factors, including leadership, reputation, and access to funding (Teece, Pisano and Shuen, 1997).

Several models have been developed to structure the NPD process. One of the earliest is the traditional sequential model, which moves linearly from idea to market launch. However, this approach often suffers from limited feedback loops and weak interdepartmental collaboration, increasing the risk of inefficiencies, rework, and missed innovation opportunities (Cooper, 1999; Owens and Cooper, 2001). A more contemporary and widely adopted alternative is the Stage-Gate model (Cooper, 2014), illustrated in

Figure , which divides the process into distinct phases (stages) separated by formal decision points (gates). This framework facilitates early evaluation, resource prioritisation, and structured risk management (Smolnik and Bergmann, 2020).

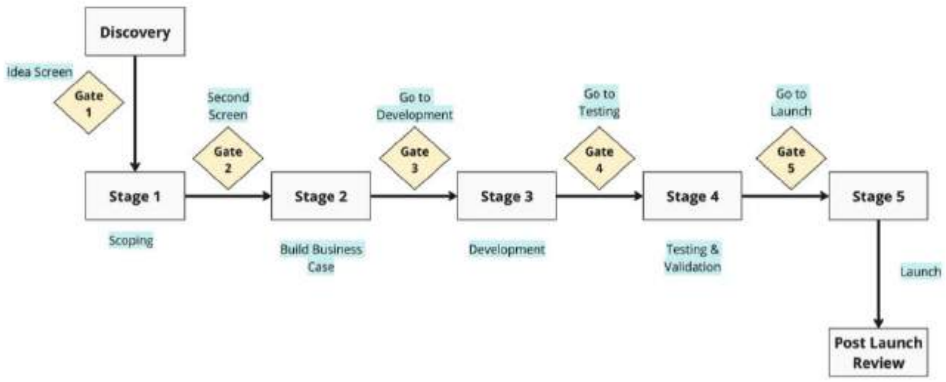

Figure 1: Overview of the Stage-Gate system by Robert Cooper, adapted from (Cooper and Edgett, 2008).

Modern adaptations of this model, such as the Triple A system (Agility, Adaptivity, Acceleration) in Figure 2, integrate iterative loops, stakeholder co-creation, and rapid prototyping to enhance responsiveness and speed (Cooper, 2014; Smolnik and Bergmann, 2020; Kruachottikul *et al.*, 2023).

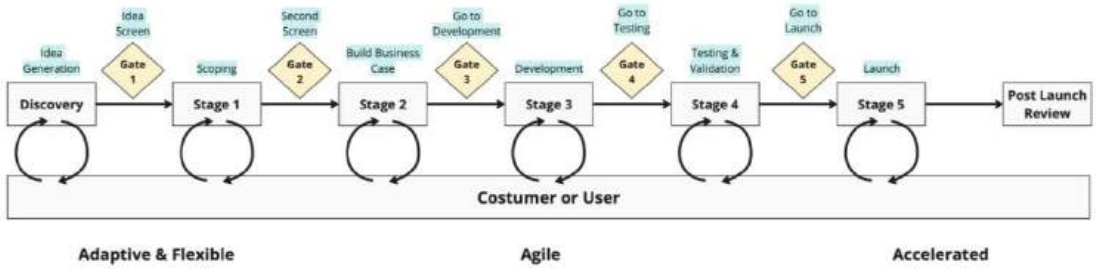

Figure 2: The next generation of the Stage-Gate process, adapted from (Cooper, 2017).

A critical phase in the innovation process is the Fuzzy Front End (FFE), which precedes formal development. This early stage involves opportunity exploration, concept generation, and strategic alignment (Pienaar et al., 2019). Despite its inherent ambiguity, the FFE can strongly influence project outcomes and success, especially for radical innovation[1] (O'Brien, 2020; Trolle, Fagerstrom and Rosio, 2020).

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[1] Radical innovation refers to breakthrough developments that lead to entirely new products, services, or technologies, often resulting in significant market or industry transformation. In contrast, incremental innovation entails gradual improvements or refinements to existing offerings, generating additional value or differentiation without disrupting existing structures (Al-Khatib and Al-ghanem, 2022).

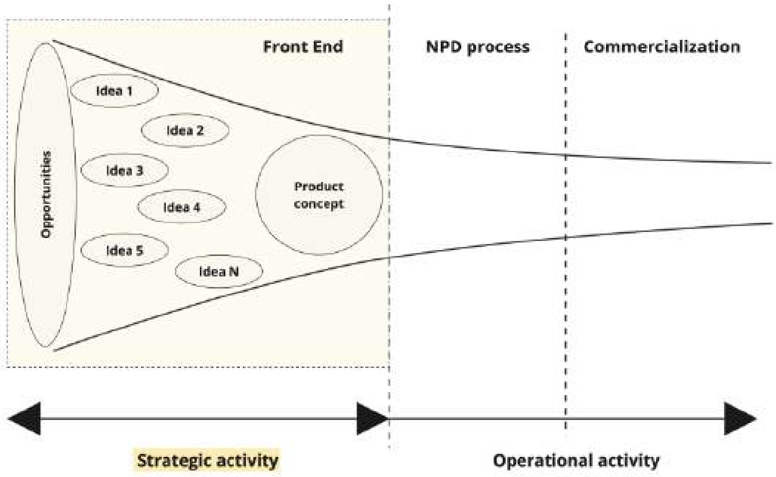

Figure 3: The Front-End phase of the innovation process.

In parallel, the increasing urgency for sustainable transition has prompted scholars and practitioners to consider the integration of environmental and social values into NPD. Sustainability-oriented innovation requires aligning products, processes, and strategies with long-term ecological objectives (Adams *et al.*, 2016; Claudy, Peterson and Pagell, 2016). Such integration demands organisational commitment, leadership support, and the ability to anticipate environmental impacts from the earliest stages of development. However, despite the availability of numerous design tools and frameworks for sustainability, their adoption and effectiveness in practice remain limited (Luttropp and Lagerstedt, 2006; Obal, Morgan and Joseph, 2020).

Integrating Circular Economy (CE) principles into NPD represents an evolution of this paradigm. CE goes beyond conventional sustainability by emphasising product lifespan extension, closed material loops, and systemic value creation (Rotondo *et al.*, 2025). This paper investigates how these principles are currently supported in literature and explores their potential integration into the NPD process to foster sustainable business innovation, particularly in the household appliance sector.

Methodology

To address the research question presented in the introduction, a systematic literature review explored the intersection between New Product Development (NPD), Circular Economy (CE), and innovation. The review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency, reproducibility, and methodological rigour (Page *et al.*, 2021).

The database used for the review was Scopus, chosen for its extensive coverage of peer-reviewed journals, conference proceedings, and books across relevant disciplines (Baas *et al.*, 2020). To capture a comprehensive spectrum of literature, a structured keyword strategy was developed based on three topics: New Product Development, Circular Economy, and Innovation. As shown in

Table , each topic included a set of synonyms and related terms, as recommended by previous studies (Marrucci, Daddi and Iraldo, 2019).

Table 1: Keywords used to conduct the systematic literature review.

Search Topics		
New Product Development	**Circular Economy**	**Innovation**
NPD	Sustainability	Business Innovation
Development Process	Closed-Loop Economy	Process Innovation
Product Development	Circular Model	Organizational Innovation
Product Design	Regenerative Economy	Strategic Innovation
Design	Circular Design	Innovation Management

Boolean operators ("OR" for synonyms and "AND" to connect concepts) were used to construct targeted queries (see Table). No restrictions were placed on publication year to ensure the inclusion of both foundational and recent contributions. The database was last updated in July 2025 to incorporate the most recent developments in the field. Three separate queries were executed, each targeting a different combination of the core topics.

Table 2: Research queries introduced to the Scopus database.

Research Queries		**Main Topics Combination**	**Results (without screening)**	**Screened results**
Query 1	**TITLE-ABS-KEY** ((New Product Development OR NPD OR Development Process OR Product Development OR Product Design OR Design) AND (Circular Economy OR Sustainability OR Closed-Loop Economy OR Circular Model OR Regenerative Economy OR Circular Design))	New Product Development + Circular Economy	289	82
Query 2	**TITLE-ABS-KEY** ((New Product Development OR NPD OR Development Process OR Product Development OR Product Design OR Design) AND (Business Innovation OR Process Innovation OR Organizational Innovation OR Strategic Innovation OR Innovation Management))	New Product Development + Innovation	681	69
Query 3	**TITLE-ABS-KEY** ((New Product Development OR NPD OR Development Process OR Product Development OR Product Design OR Design) AND (Circular Economy OR Sustainability OR Closed-Loop Economy OR Circular Model OR Regenerative Economy OR Circular Design) AND (Innovation OR Business Innovation OR Process Innovation OR Organizational Innovation OR Strategic Innovation OR Innovation Management))	New Product Development + Circular Economy + Innovation	33	8

The initial search returned 1003 results. Figure 4 shows that duplicate and irrelevant articles were removed during the screening phase. The inclusion criteria focused on: (i) English-language articles, (ii) journal publications, and (iii) subject areas relevant to design, engineering, management, environmental science, and innovation studies. Articles from disciplines such as medicine or agriculture were excluded.

After removing duplicates and applying filters, 145 papers remained. A further screening of titles and abstracts reduced this to 73 papers. Following a full-text assessment, 47 articles were selected for in-depth review and qualitative synthesis.

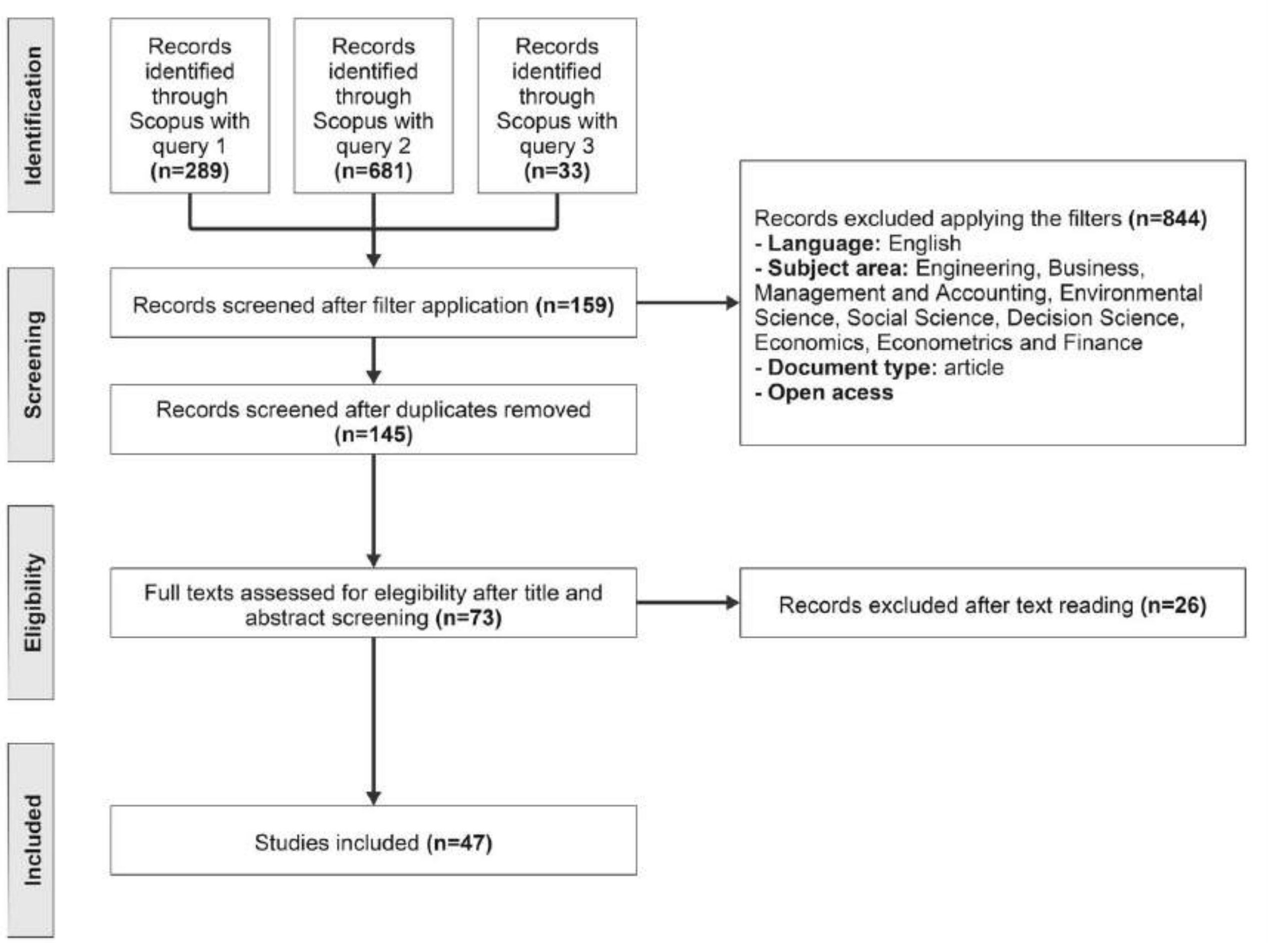

Figure 4: Overview of the systematic literature review performed adopting PRISMA methodology.

Specifically, the analysis was conducted using Microsoft Excel to ensure a structured approach to data synthesis. A complete list of these articles is available in Annex.

During the data collection phase, prevailing themes emerged in the literature. Keyword co-occurrences were mapped using VosViewer software to effectively capture the primary arguments (van Eck and Waltman, 2017). This allowed the identification of emerging clusters, highlighting the most recurrent concepts and gaps in the existing literature.

Results

A total of 40 articles were selected through the systematic review process and analysed in depth to identify emerging themes, barriers, and opportunities in integrating Circular Economy (CE) principles into New Product Development (NPD) for sustainable business innovation. The analysis considered keyword co-occurrence, publication trends, geographical distribution, methodological approaches, and citation impact.

As shown in Figure , the keyword co-occurrence network highlights "circular economy" as the central node, closely related to key concepts such as "sustainability," 'innovation,' "business model innovation," and "new product development." This indicates that the circular economy is often framed within broader discussions of sustainable innovation and industrial transformation. Other prominent clusters are “industry 4.0”, “digitisation” and “design,” which indicate the growing importance of digital technologies and design practices in enabling circular transitions. Notably, terms such as “circular design” and “circular business models” appear more recent, as indicated by their colouration in the 2022-2023 range, suggesting emerging areas of scholarly attention. These results reinforce the intertwined nature of technological, strategic, and design dimensions in the integration of circular principles into product innovation and development processes.

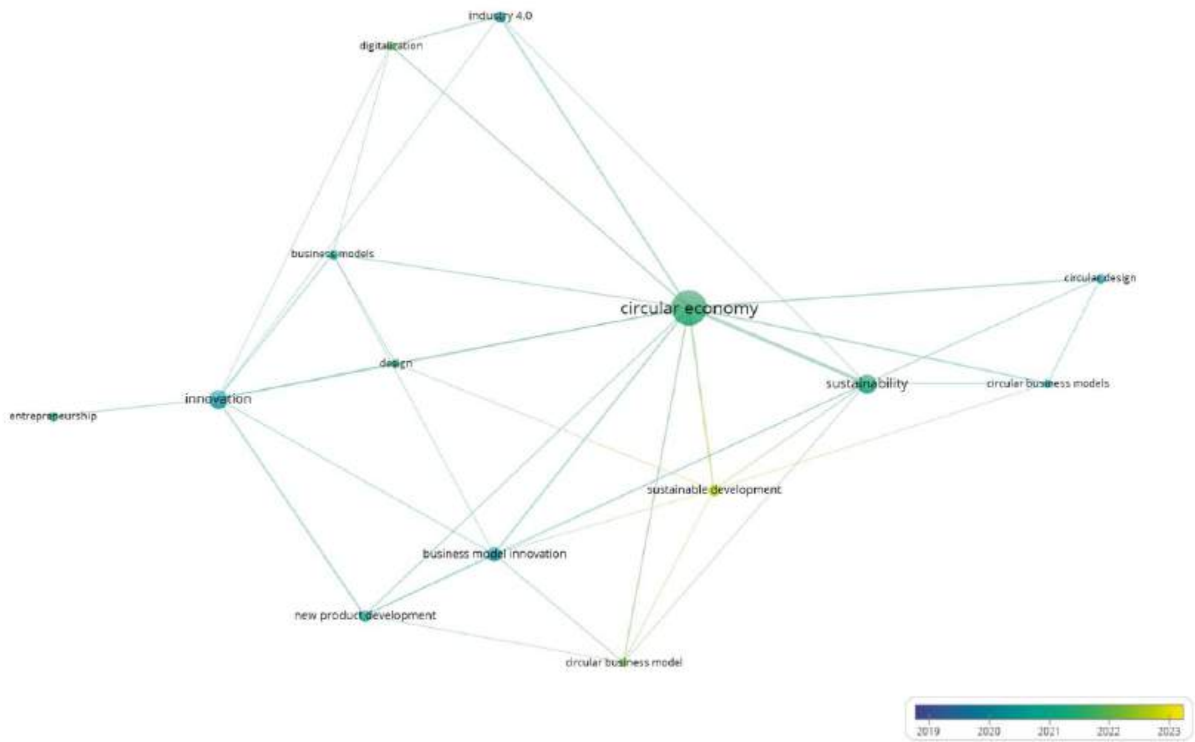

Figure 5: Co-occurrence network of keywords.

The temporal distribution of the selected studies (Figure) reveals a steep rise in publications from 2018 onward, with peaks in 2021 (7 papers), 2022 (7 papers), 2023 (8 papers) and 2024 (7 papers). The upward trend suggests an intensifying academic focus on the convergence of CE, innovation, and NPD, especially following policy advances such as the European CEAP and ESPR. A slight decline in 2020 is likely attributable to COVID-19-related disruptions. Only one article was found for 2025, but this number is expected to rise as the year progresses.

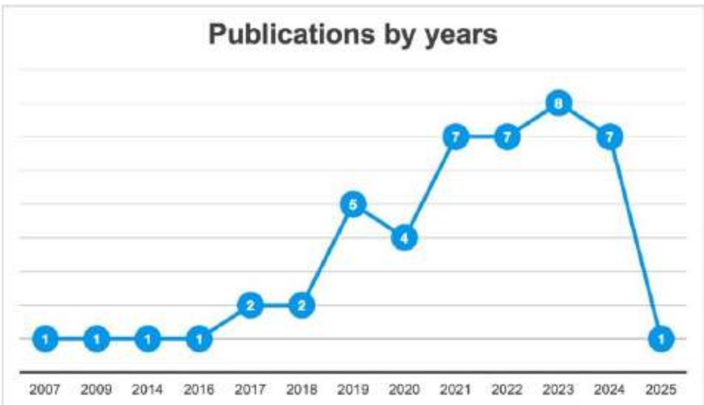

Figure 6: Number of publications by years.

The geographical analysis (Figure and Table 3) confirms that Europe dominates the research landscape, particularly the United Kingdom and the Netherlands. In particular, several studies originated from the Faculty of Industrial Design Engineering at TU Delft, with prominent authors such as Conny Bakker and Ruud Balkenende. Their work is renowned for promoting circular design strategies and product-service systems for resource loops, such as product lifetime extension, repair, and remanufacturing. Other contributions came from Brazil, Indonesia, Taiwan, and Australia, indicating a growing global engagement.

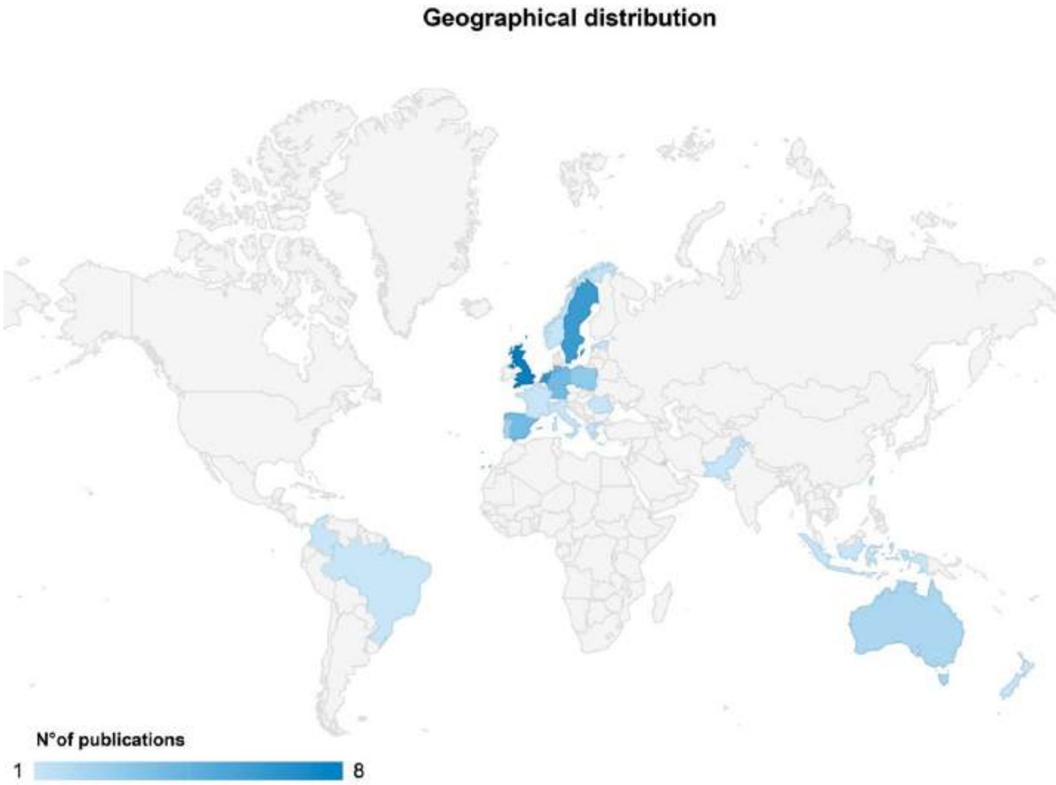

Figure 7: Distribution of publications by country.

Table 3: Number of publications by country.

Country	N° of publications
Regno Unito	8
Paesi Bassi	6
Svezia	6
Spagna	4
Germania	4
Polonia	3
Portogallo	2
Australia	2
Colombia	1
Indonesia	1
Kuwait	1
Italia	1
Nuova Zelanda	1
Grecia	1
Brasile	1
Taiwan	1
Norvegia	1
Francia	1
Estonia	1
Pakistan	1
Romania	1

Regarding research design (Figure 8), most of the studies (53%) adopted a qualitative methodology, commonly based on case studies, literature reviews, and expert interviews. Around 34% employed mixed methods, combining qualitative insights with quantitative techniques such as surveys or performance analysis. In contrast, purely quantitative studies were relatively few (13%). This distribution reflects the complexity of integrating circular economy principles into business and design practices, highlighting the need for exploratory and context-sensitive approaches. It also suggests that while empirical validation is important, understanding organisational dynamics and innovation processes often requires qualitative depth.

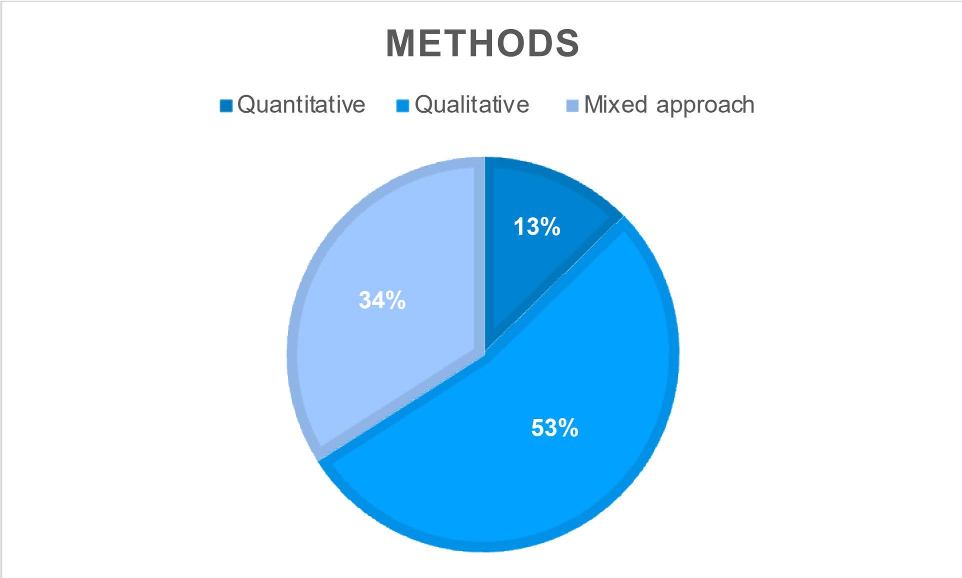

Figure 8: Methodological approaches.

Lastly, Table 4 highlights the most cited articles in the corpus. The top-ranked publication, "A conceptual framework for circular design" by Moreno et al. (2016), has received 327 citations. It explores the role of design in enabling closed-loop product strategies and the development of frameworks for integrating design-for-sustainability with circular business models. Other highly cited works also reflect this focus on operationalising circularity through design and business model innovation, reinforcing the relevance of design-led approaches in achieving CE goals.

Table 4: More cited articles from the systematic literature review.

Authors	Title	Year	Source title	Citations
Moreno M., De los Rios C., Rowe Z., Charnley F.	A conceptual framework for circular design	2016	Sustainability (Switzerland)	327
Magnusson P.R.	Exploring the contributions of involving ordinary users in ideation of technology-based services	2009	Journal of Product Innovation Management	243
Mendoza J.M.F., Sharmina M., Gallego-Schmid A., Heyes G., Azapagic A.	Integrating Backcasting and Eco-Design for the Circular Economy: The BECE Framework	2017	Journal of Industrial Ecology	217
Baldassarre B., Schepers M., Bocken N., Cuppen E., Korevaar G., Calabretta G.	Industrial Symbiosis: towards a design process for eco-industrial clusters by integrating Circular Economy and Industrial Ecology perspectives	2019	Journal of Cleaner Production	202
Garcia-Muiña F.E., González-Sánchez R., Ferrari A.M., Settembre-Blundo D.	The paradigms of Industry 4.0 and circular economy as enabling drivers for the competitiveness of businesses and territories: The case of an Italian ceramic tiles manufacturing company	2018	Social Sciences	151
Konietzko J., Bocken N., Hultink E.J.	A tool to analyze, ideate and develop circular innovation ecosystems	2020	Sustainability (Switzerland)	101
Sehnem S., de Queiroz A.A.F.S.L., Pereira S.C.F., dos Santos Correia G., Kuzma E.	Circular economy and innovation: A look from the perspective of organizational capabilities	2022	Business Strategy and the Environment	72

Discussions

The systematic literature review has highlighted several critical themes highly relevant to companies aiming to integrate sustainability and circular economy (CE) principles into their new product development (NPD) processes. This is especially urgent in the household appliance sector, where resource consumption and electronic waste generation are particularly impactful (Blagu *et al.*, 2022).

Circular Economy in the NPD Process

Several studies underscore the necessity of aligning NPD with CE principles to drive sustainable innovation (Nyström *et al.*, 2021). However, the integration of circularity into NPD processes, beyond adopting circular business models (CBMs), remains limited and fragmented (Aguiar and Jugend, 2022). CBMs are built on extending product life, intensifying usage, and reducing material flows through reuse, recycling, and service-based strategies (Geissdoerfer *et al.*, 2020). These models provide an alternative to traditional linear systems, and when embedded within the NPD process, they support a systemic approach to reducing environmental impact while generating economic value (Wójcik-Karpacz *et al.*, 2023).

Circular Product Design (CPD) is central to this shift. It diverges significantly from traditional product development by incorporating strategies such as modularity, reparability, and shared usage models (Moreno *et al.*, 2016; Aguiar and Jugend, 2022). Boyer et al. (2021) define product circularity based on three criteria: recirculation of materials, increased use frequency, and preservation of functionality over time. These require designers to consider physical and emotional durability, fostering longer product attachment (Selvefors *et al.*, 2019). Design-for-X strategies offer a practical framework for implementing these principles, including design for reuse, remanufacturing, disassembly, and recycling (Mendoza *et al.*, 2017). These strategies are especially relevant in sectors characterised by complex product architectures, such as electronics and household appliances (Williams and Shittu, 2022).

Moreover, several studies present structured design methodologies that combine environmental impact assessment (e.g., LCA) with modular platform development and optimisation techniques, supporting CE integration through technical rigour and digital tools (Ruiz-Pastor *et al.*, 2022; Córdoba-Roldán *et al.*, 2024). These contributions demonstrate how CE is progressively shifting from conceptual ambition to operational practice, particularly when embedded into design processes through interdisciplinary collaboration.

In parallel, early-stage design activities, such as material selection, energy efficiency, and waste prevention, remain decisive in determining a product's overall sustainability impact (Albæk *et al.*, 2020; Ruiz-Pastor *et al.*, 2021). As these activities grow increasingly complex, they demand not only structured methodologies but also the development of new design competencies. In this regard, several authors highlight the critical role of cross-functional collaboration and the upskilling of design teams. The ability to think systemically, engage with lifecycle considerations, and navigate organisational complexity is recognised as essential for designers operating in CE-aligned NPD processes (De los Rios and Charnley, 2017; Sumter *et al.*, 2021).

Role of the Designer

Designers are pivotal in the CE transition, particularly in product development phases where critical sustainability decisions are made. Their role extends beyond aesthetics, including material choices, modularity, emotional durability, and lifecycle performance (Dokter, Thuvander and Rahe, 2021; Alkouh, Keddar and Alatefi, 2023). CPD enables more flexible and sustainable resource use, reduces environmental burdens, and enhances consumer acceptance of circular solutions (Yi and Wu, 2021; Burke, Zhang and Wang, 2023).

As highlighted by Luttropp and Lagerstedt (2006), sustainable design maximises product utility while minimising environmental and economic costs (Luttropp and Lagerstedt, 2006). Designers are expected to engage in user-centred strategies such as Design for Sustainable Behaviour (DfSB), which promotes responsible user interaction throughout the product's lifecycle (Bhamra, Lilley and Tang, 2011; Shin and Bull, 2019).

Moreover, the designer's role is evolving from product creator to a system thinker and strategic facilitator. Circular Systems Thinking, a competence emphasised by Sumter et al. (2021), requires designers to assess the systemic implications of their interventions. Other crucial competencies include designing for multiple life cycles, enabling business model innovation, and facilitating stakeholder co-creation (Dokter, Thuvander and Rahe, 2021).

Electronic Product Design and Circular Strategies in the Home Appliance Sector

Electronic products, particularly in the household appliance sector, pose unique design challenges due to their material complexity, technological obsolescence, and difficulties in disassembly and recyclability. Achieving circularity in this context requires carefully selecting recyclable and non-toxic materials, modular architecture, and updatable software systems to extend product life (Williams and Shittu, 2022; Alkouh, Keddar and Alatefi, 2023). For example, Fairphone's modular mobile phones enable repair, reuse, and extended use, demonstrating the potential of CPD in the electronics sector (Bressanelli *et al.*, 2020).

Major home appliance manufacturers are also embracing circular strategies. Electrolux aims for net-zero emissions by 2050 and has launched circular take-back programs and sustainable packaging initiatives (Electrolux, 2024). De'Longhi focuses on sustainable product design and collaborates with universities to drive innovation in lifestyle-aligned appliances (De' Longhi Group, 2022). Jura emphasises product longevity and recyclability, while Smeg integrates recycled materials into its product and packaging design (SMEG S.p.A., 2023). Other examples include Whirlpool's user-centred energy-saving technologies and Samsung's focus on material recovery and e-waste innovation (Samsung, 2025; Whirlpool Corporation, 2025).

These cases illustrate how sustainability can be embedded in product features, business strategies, and customer experiences, paving the way for scalable CE integration. Moreover, the convergence between CE and Industry 4.0 is gaining traction in this sector. Some studies illustrate how smart appliances integrated with IoT, digital twins, and product passports can support extended use cycles and traceability of materials, thus enhancing the circular potential of electronic product systems (Garcia-Muiña *et al.*, 2018; Toth-Peter *et al.*, 2023).

Opportunities

The literature reveals multiple opportunities for integrating CE in NPD:

- Sustainable product strategies contribute to differentiation, regulatory compliance, and resource security (Burke, Zhan
- g and Wang, 2023).
- Circular business models enhance brand equity, enable new revenue streams, and improve customer engagement (Wójcik-Karpacz *et al.*, 2023).
- Tailored eco-design tools help disseminate CE principles across departments and increase tool usability (Yi and Wu, 2021; Córdoba-Roldán *et al.*, 2024).
- Environmental checkpoints, such as design reviews and milestone tracking, ensure sustainability goals remain prioritised (Córdoba-Roldán et al., 2024).
- Strong managerial support and top-down communication foster cultural alignment around CE values (Altuntas Vural *et al.*, 2024; Schneider *et al.*, 2024).
- Low-cost eco-efficiency strategies, particularly beneficial for SMEs, lead to short-term returns while reducing environmental burdens (Vihma and Moora, 2020; Vásquez, Gallego and Soto, 2024).
- Lean Manufacturing and Industry 4.0 technologies enhance agility and support digital circularity through tools such as IoT, AI, and big data (Toth-Peter *et al.*, 2023; Vásquez, Gallego and Soto, 2024).
- Product-service systems (PSS) offer service-based models like leasing or pay-per-use that decouple ownership from consumption (Vezzoli *et al.*, 2018; Batlles-delaFuente *et al.*, 2022).
- Creative and user-centred design practices support the combination of sustainability with emotional and functional value, fostering product attachment and extended use (Yi and Wu, 2021).

Together, these elements form a roadmap for embedding circularity into business models, design practices, and organisational structures.

Barriers

Despite its potential, the transition to circular NPD is hindered by several persistent barriers:

- Lack of clearly defined goals and integration mechanisms, particularly in the early design stages (Boks, 2006).

- Increased complexity in design processes due to the addition of sustainability dimensions and the involvement of new stakeholders (Aguiar and Jugend, 2022).
- Organisational silos and a lack of cross-departmental coordination impede systemic integration (Li and Roy, 2015).
- Limited access to financial resources and technological infrastructures limits experimentation with CE models (Vásquez, Gallego and Soto, 2024).
- Skill shortages, knowledge gaps, and misconceptions about CE prevent organisations from engaging deeply with sustainability practices (Toth-Peter *et al.*, 2023).
- Digital transition gaps, such as fragmented infrastructure and data-sharing challenges, hinder the adoption of Industry 4.0 technologies (Garcia-Muiña *et al.*, 2018; Toth-Peter *et al.*, 2023).
- Complexity of product-service systems (PSS) and lack of clear partner ecosystems hinder implementation (Dokter, Thuvander and Rahe, 2021)

Overcoming these challenges requires multi-stakeholder collaboration, policy support, dedicated resources, and education and training initiatives to cultivate circular mindsets across departments.

Conclusions

From the systematic literature review and the discussions presented, several key conclusions emerge regarding implementing circular economy principles in product development processes, focusing on companies in the home appliance sector.

- Empirical analysis is crucial to instil confidence among companies in the electrical and electronics sector in adopting these new approaches, highlighting the need for reliable data to support decision-making processes. The definition of clear guidelines on effectively managing and implementing these approaches in practice is crucial for companies' long-term competitiveness in this sector.
- Interdisciplinary teams with the ability to collaborate, accept diverse perspectives, and acquire external knowledge are necessary for successful implementation, especially in home appliance companies. Integrating customer knowledge into the product development process in this sector can lead to significant benefits, reducing time and costs for bringing new products to market and improving customer satisfaction.
- Companies in the electrical and electronics sector can overcome technological, financial, organisational, and knowledge barriers by adopting preventive, simple, cost-effective, and complementary green technologies. Social and environmental awareness among consumers and appropriate legal regulations are crucial for successfully implementing circular business models in this sector.
- The involvement of designers is crucial in the home appliance sector, as they must address new challenges requiring specific knowledge, strategies, and methods. Companies in this area need to integrate aspects of circularity from the product development process's early stages (fuzzy front-end phase), with particular attention to all its life cycle stages.

However, it is essential to recognise the limitations of this study, including the use of specific keywords, a single database for research methods and potential subjectivity in data analysis.

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Appendix

Annex 1: Included papers from the systematic literature review.

Authors	Title	Year	Source title	Citations
Mahmood S.; Iqbal A.; El-Kenawy E.M.; Eid M.M.; Alhussan A.A.; Sami Khafaga D.	The impact of green technology innovation, pro-environmental behavior and eco-design on green new product success: examine the moderating role of green corporate image	2025	Environmental Research Communications	1
Vásquez P., Gallego V., Soto J.D.	Transforming MSMEs towards circularity: an attainable challenge with the appropriate technologies and approaches	2024	Environment Systems and Decisions	1
Córdoba-Roldán A.; Martín-Gómez A.M.; Rodríguez-Núñez M.; Lama-Ruiz J.R.	An Evolutionary Modular Product Development Under Circular Economy Approach	2024	Sustainability (Switzerland)	0
Schneider M.H.G.; Kanbach D.K.; Kraus S.; Dabic M.	Transform Me If You Can: Leveraging Dynamic Capabilities to Manage Digital Transformation	2024	IEEE Transactions on Engineering Management	22
Altuntas Vural C.; Balci G.; Surucu Balci E.; Gocer A.	Looking inside the panarchy: reorganisation capabilities for food supply chain resilience against geopolitical crises	2024	Supply Chain Management	2
Klemm C.; Kaufman S.	The importance of circular attributes for consumer choice of fashion and textile products in Australia	2024	Sustainable Production and Consumption	11
Gorokhova T.; Kozlova A.; Laguta Y.; Skrashchuk L.; Kaminskyi S.	The Role of the Circular Economy in Advancing Environmentally Sustainable Industrial Production	2024	Grassroots Journal of Natural Resources	0
Istrițeanu S.; Badea F.; Bâjenaru V.	ECO-INNOVATION AND ECO-DESIGN IN THE CURRENT AUTOMOTIVE INDUSTRY	2024	International Journal of Mechatronics and Applied Mechanics	1
Fatimah Y.A., Kannan D., Govindan K., Hasibuan Z.A.	Circular economy e-business model portfolio development for e-business applications: Impacts on ESG and sustainability performance	2023	Journal of Cleaner Production	14
Alkouh A., Keddar K.A., Alatefi S.	Revolutionizing Repairability of Industrial Electronics in Oil and Gas Sector: A Mathematical Model for the Index of Repairability (IOR) as a Novel Technique	2023	Electronics (Switzerland)	2
Sabatini A., Pascucci F., Gregori G.L.	Customer involvement in technological development of smart products: empirical evidence from a coffee-machine producer	2023	Journal of Business and Industrial Marketing	1
Toth-Peter A., Torres de Oliveira R., Mathews S., Barner L., Figueira S.	Industry 4.0 as an enabler in transitioning to circular business models: A systematic literature review	2023	Journal of Cleaner Production	18
Blomsma F., Tennant M., Ozaki R.	Making sense of circular economy: Understanding the progression from idea to action	2023	Business Strategy and the Environment	9
Azcárate-Aguerre J.F., den Heijer A.C., Arkesteijn M.H., Vergara d'Alençon L.M., Klein T.	Facades-as-a-Service: Systemic managerial, financial, and governance innovation to enable a circular economy for buildings. Lessons learnt from a full-scale pilot project in the Netherlands	2023	Frontiers in Built Environment	2
Wójcik-Karpacz A., Karpacz J., Brzeziński P., Pietruszka-Ortyl A., Ziębicki B.	Barriers and Drivers for Changes in Circular Business Models in a Textile Recycling Sector: Results of Qualitative Empirical Research	2023	Energies	5
Burke H., Zhang A., Wang J.X.	Integrating product design and supply chain management for a circular economy	2023	Production Planning and Control	27
Williams I.D., Shittu O.S.	Development of sustainable electronic products, business models and designers using circular economy thinking	2022	Detritus	1
Bimpizas-Pinis M., Calzolari T., Genovese A.	Exploring the transition towards circular supply chains through the arcs of integration	2022	International Journal of Production Economics	8
Averina E., Frishammar J., Parida V.	Assessing sustainability opportunities for circular business models	2022	Business Strategy and the Environment	20
Ruiz-Pastor L., Chulvi V., Mulet E., Royo M.	A metric for evaluating novelty and circularity as a whole in conceptual design proposals	2022	Journal of Cleaner Production	19
Salwin M., Nehring K., Jacyna-Gołda I., Kraslawski A.	PRODUCT-SERVICE SYSTEM DESIGN: AN EXAMPLE OF THE LOGISTICS INDUSTRY	2022	Archives of Transport	2
Bofylatos S.	Upcycling Systems Design, Developing a Methodology through Design	2022	Sustainability (Switzerland)	5
Sehnem S., de Queiroz A.A.F.S.L., Pereira S.C.F., dos Santos Correia G., Kuzma E.	Circular economy and innovation: A look from the perspective of organizational capabilities	2022	Business Strategy and the Environment	72
Batlles-delafuente A., Belmonte-ureña L.J., Plaza-úbeda J.A., Abad-segura E.	Sustainable business model in the product-service system: Analysis of global research and associated eu legislation	2021	International Journal of Environmental Research and Public Health	6
Yi S., Wu C.-F.	Green-extension design—a new strategy to reduce the environmental pressure from the existing consumer electronics	2021	International Journal of Environmental Research and Public Health	5
Dokter G., Thuvander L., Rahe U.	How circular is current design practice? Investigating perspectives across industrial design and architecture in the transition towards a circular economy	2021	Sustainable Production and Consumption	66
Ortega Alvarado I.A., Sutcliffe T.E., Berker T., Pettersen I.N.	Emerging circular economies: Discourse coalitions in a Norwegian case	2021	Sustainable Production and Consumption	29
van Loon P., Diener D., Harris S.	Circular products and business models and environmental impact reductions: Current knowledge and knowledge gaps	2021	Journal of Cleaner Production	50
Evrard D., Rejeb H.B., Zwolinski P., Brissaud D.	Designing immortal products: A lifecycle scenario-based approach	2021	Sustainability (Switzerland)	4
Sumter D., de Koning J., Bakker C., Balkenende R.	Key competencies for design in a circular economy: Exploring gaps in design knowledge and skills for a circular economy	2021	Sustainability (Switzerland)	36
Lugnet J., Ericson Å., Larsson T.	Design of product–service systems: Toward an updated discourse	2020	Systems	15
Vihma M., Moora H.	Potential of Circular Design in Estonian SMEs and their Capacity to Push it	2020	Environmental and Climate Technologies	12
Miller C., Thomas B.C., Roeller M.	Innovation management processes and sustainable iterative circles: an applied integrative approach	2020	Journal of Work-Applied Management	9
Konietzko J., Bocken N., Hultink E.J.	A tool to analyze, ideate and develop circular innovation ecosystems	2020	Sustainability (Switzerland)	101
Hankammer S., Brenk S., Fabry H., Nordemann A., Piller F.T.	Towards circular business models: Identifying consumer needs based on the jobs-to-be-done theory	2019	Journal of Cleaner Production	53
Singh J., Cooper T., Cole C., Gnanapragasam A., Shapley M.	Evaluating approaches to resource management in consumer product sectors - An overview of global practices	2019	Journal of Cleaner Production	21
Baldassarre B., Schepers M., Bocken N., Cuppen E., Korevaar G., Calabretta G.	Industrial Symbiosis: towards a design process for eco-industrial clusters by integrating Circular Economy and Industrial Ecology perspectives	2019	Journal of Cleaner Production	202
Ziemba E., Eisenbardt M., Mullins R., Dettmer S.	Prosumers' engagement in business process innovation – the case of Poland and the UK	2019	Interdisciplinary Journal of Information, Knowledge, and Management	11
Ferreira I.A., Fraga M.C., Godina R., Barreiros M.S., Carvalho H.	A proposed index of the implementation and maturity of circular economy practices-the case of the pulp and paper industries of Portugal and Spain	2019	Sustainability (Switzerland)	23
Garcia-Muiña F.E., González-Sánchez R., Ferrari A.M., Settembre-Blundo D.	The paradigms of Industry 4.0 and circular economy as enabling drivers for the competitiveness of businesses and territories: The case of an Italian ceramic tiles manufacturing company	2018	Social Sciences	151
Sumter D., Bakker C., Balkenende R.	The role of product design in creating circular business models: A case study on the lease and refurbishment of baby strollers	2018	Sustainability (Switzerland)	59
Vogtlander J.G., Scheepens A.E., Bocken N.M.P., Peck D.	Combined analyses of costs, market value and eco-costs in circular business models: eco-efficient value creation in remanufacturing	2017	Journal of Remanufacturing	57
Mendoza J.M.F., Sharmina M., Gallego-Schmid A., Heyes G., Azapagic A.	Integrating Backcasting and Eco-Design for the Circular Economy: The BECE Framework	2017	Journal of Industrial Ecology	217
Moreno M., De los Rios C., Rowe Z., Charnley F.	A conceptual framework for circular design	2016	Sustainability (Switzerland)	327
Marques P.C., Cunha P.F.	Integrating product-service systems with new business models definition for manufacturing industries	2014	International Journal of Service Science, Management, Engineering, and Technology	6
Magnusson P.R.	Exploring the contributions of involving ordinary users in ideation of technology-based services	2009	Journal of Product Innovation Management	243
Owens J.D.	Why do some UK SMEs still find the implementation of a new product development process problematical?: An exploratory investigation	2007	Management Decision	51

Affecting and Affected: B Corp Representations of the Environment as a Stakeholder

Mark Ryan

Researcher

Lancaster University

United Kingdom

Businesses increasingly frame themselves as environmentally responsible, yet questions remain about how organisations conceptualise the environment and its relationship to business outcomes. In line with the dominant stakeholder theory criteria of "can affect or is affected by the achievement of the firm's objectives" (Freeman, 1984, p. 25), the natural environment has been debated as a potential stakeholder. Despite its salience in sustainability discourse, the environment remains marginal in stakeholder theory, often considered too diffuse or passive to qualify as a true stakeholder. B Corporations (B Corps) provide a particularly interesting context to investigate these issues. These firms commit to balancing profit and purpose (Stubbs, 2017), and the certification process emphasises accountability to a broad set of stakeholders, including the environment. However, little is known about how B Corps represent the environment in practice. This study therefore investigates how B Corps describe the environment in their stakeholder representations and what this reveals about the environment's role as a stakeholder.

Various arguments have been made for (e.g., Starik, 1995) and against (e.g., Phillips and Reichart, 2000) the inclusion of the environment as a stakeholder. Arguments for inclusion highlight interdependence: firms rely on environmental resources, and environmental degradation directly affects business outcomes. On the other hand, critics argue that the environment lacks agency, voice, or negotiability, making its classification as a stakeholder problematic. This paper contributes to these debates by providing systematic empirical evidence from B Corps that explicitly commit to stakeholder orientation. Whereas previous work has largely been conceptual, this analysis demonstrates how firms themselves frame the environment in public descriptions. In doing so, the study provides insights into whether and how the environment is treated as a stakeholder in practice. Beyond stakeholder theory, the paper also investigates the relationship between environmental representation and outcomes, highlighting tensions between symbolic and substantive sustainability commitments.

The paper draws on a dataset of 17,875 certified B Corporations that explicitly mention the environment in their descriptions. Four key terms commonly used to denote the environment (*planet*, *earth*, *nature*, and *environment*) were identified and used to determine firms representing the environment as a stakeholder. This produced a sample of 2,440 firms, representing 13.7% of the total B Corp database at the time of data collection. Textual data was coded into a framework based on how firms affect and are affected by the environment. This revealed four categories: direct environmental impacts (environmental improvements and harm reductions), indirect environmental impacts (supporting and inspiring stakeholders), environmental benefits to firms (tangible and intangible benefits), and unclear environmental impacts (value-based and vague statements).

The analysis revealed three key patterns. First, most B Corps describe the environment primarily as something that the firm affects. Explicit references to the environment affecting the firm (e.g., dependence on natural resources) were rare. This suggests that, even in a stakeholder-oriented certification context, the environment is constructed more as a recipient of corporate action than an active influence on businesses. Second, the largest share of representations of how firms affect the environment was vague mentions without clear actions or outcomes, signifying symbolic alignment only. When clear strategies were indicated, they most commonly spoke of reductions, such as lowering emissions or waste, rather than regenerating resources. Indirect environmental benefits (i.e., benefitting another stakeholder, who in turn affects the environment) were also relatively rare. Third, exploratory analysis of B Impact Assessment scores suggests that firms clearly describing their environmental impacts and acknowledging their dependence on nature tended to outperform those with vague mentions. However, firms with more detailed environmental commitments often scored lower on social metrics, hinting at tensions between environmental and social priorities and trade-offs in the certification process.

These findings have several implications. For stakeholder theory, they demonstrate that the environment is often treated as if it were a stakeholder by firms themselves, yet in practice it is typically framed passively (e.g., as something to be protected or regenerated) rather than as an active agent shaping organisational outcomes. This partial recognition may help explain why the environment remains contested within stakeholder scholarship. For B Corps, the findings highlight limitations related to environmental certification. Such processes may encourage symbolic mentions of the environment without ensuring concrete outcomes are achieved, risking greenwashing (Carlson *et al.*, 1993). More broadly, the study contributes to understanding tensions in sustainability transitions. Firms that engage more deeply with environmental concerns may face trade-offs with other stakeholder commitments, suggesting the environmental value cannot always be aligned seamlessly with social and economic goals (Van der Byl and Slawinski, 2015). Recognising these tensions is vital for designing certification and governance systems that move beyond symbolic compliance toward substantive environmental outcomes.

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Product Circularity, Strategies, Indicators and Challenges: Insights from Industry

Lilian Sanchez Moreno

Post Doctoral Research Fellow

University for the Creative Arts

United Kingdom

The use of the concept of 'circularity' within government, policy, industry, and academia, has grown exponentially in the last decade, alongside a growth in the development of tools and methodologies to measure circularity. However, the levels of implementation and measurement of product circularity across industry remain unknown. The Centre for Sustainable Design ® at the University for the Creative Arts conducted 21 in-depth qualitative interviews with companies that claimed to have a core circular economy business strategy. The data collected from the interviews was analyzed using a thematic coding methodology to 1) gain insights into how product circularity (PC) is understood by industry, PC strategies currently being implemented across various sectors; 2) identify barriers for implementation that can enable further discussions for theoretical and conceptual innovations for remanufacturing, reuse, refurbish and repair and new ways for production and consumption, and 3) contribute to the development of methodologies and tools for measuring product circularity beyond recycled inflows and outflows. A key finding was the lack of harmonization of the concept of PC and CE more generally across different sectors. Moreover, to date, the development of methodologies that seek to quantitively assess PC performance for internal decision making and external communications, have focused primarily on assessing the use of recycled material inflows and outflows; thus, positioning circularity as synonymous to recycling. Conversely, measuring use phase related PC issues e.g., repair, reuse, etc. is still in the early stages due to a lack of data on customer use by companies.

Comparative Analysis of Decarbonisation Pathways of Electric and Fuel Powered Vehicles

Dr Muhammad Shafique

Department of Civil and Environmental Engineering

Brunel University of London

United Kingdom

Over the last two decades, the transport sector has been one of the leading sources of carbon emissions. Several efforts have been made to mitigate the carbon emissions from the sector. Battery Electric Vehicles and Hydrogen Fuel Cell Vehicles play a pivotal role in decarbonising the transport sector and mitigating climate change. The study refines the Well-to-Wheel (WTW) assessment model to account for dynamic energy systems, including evolving energy mixes and interregional energy trade. The enhanced model improves data precision, reflecting technological progress and regional variability in energy use and emissions. Result analysis indicated that the future vehicles deployed in 2040 are projected to reduce WTW emissions by over 50% compared to those from 2030, depending on location-specific energy developments. The varying degrees of reduction are influenced by a variety of factors, including the transition to cleaner energy sources, cross-regional trading of alternative fuels, and variations in annual vehicle driving distances. Moreover, emissions performance varies substantially across regions, depending on local energy sources and infrastructure. For instance, areas with coal-dependent grids show higher emissions than those powered predominantly by renewables, highlighting the importance of localised energy contexts.

These findings underscore the urgent need for regionally differentiated policies that align with local energy conditions and mobility patterns, aiming for continuing sustainability. Effective strategies should promote cross-regional energy cooperation and remain adaptable to future technological and market developments. The enhanced WTW model offers a robust foundation for designing targeted, forward-looking environmental policies and supports more informed decision-making in the transition to sustainable transportation systems worldwide.

For policymakers, the findings stress the importance of enabling flexible, region-specific energy and transport policies, particularly those that incentivise clean energy deployment, support cross-regional energy trade, and align infrastructure development with emissions goals. For engineers and system designers, the enhanced WTW model offers a valuable tool for evaluating the real-world impact of vehicle technologies and energy integration strategies. By bridging technical accuracy with policy relevance, this study provides a robust scientific foundation for guiding long-term investments in sustainable mobility systems and supporting more precise, data-driven climate action.

Transparency in Care Labels: the Key Enabler for a Circular Fashion System

Beatrice Soncina

Sustainability Consultant

Self-employed

Italy

Abstract

Investigating material transparency, regulatory gaps, and design strategies for sock design

As calls for circularity reshape the fashion industry, socks pose a unique challenge. They are rarely designed with end-of-life scenarios in mind, and current EU labelling regulations permit the omission of fibres used in key structural areas, thereby compromising transparency and recyclability. A Research through Design (RtD) approach led to investigate how regulatory constraints, design practices, and material choices intersect in the development of a recyclable and compostable sock prototype. Semi-structured interviews with experts in circularity, materials, and sock manufacturing informed an iterative design process. The project reveals significant gaps between regulatory labelling requirements and the material reality of garments. It demonstrates that circularity in such items is possible but requires mono-material design, improved transparency mechanisms, and regulatory reform. The study also discusses the future potential of the Digital Product Passport (DPP) as a tool to address these systemic issues and enhance traceability in the fashion supply chain.

Introduction and literature review

This research addresses a simple yet undervalued artefact, and its potential for circularity. How can socks be designed to be recyclable or compostable? Adopting a Research through Design (RtD) approach, the study investigates how design decisions and labelling regulations can hinder or enable circularity. The development of a sock prototype that aligns with circular design principles serves as a framework to examine broader systemic barriers in circular fashion.

Circular economy frameworks and material flow principles

The textile industry is a major contributor to global greenhouse gas emissions, with raw material production alone responsible for approximately 38% of the sector's total emissions (McKinsey & Company and Global Fashion Agenda 2021). As environmental pressures intensify and planetary boundaries are increasingly exceeded, the need for a systemic transformation of the industry has become urgent. A shift towards a circular economy is a promising pathway—one that could reduce the sector's total emissions by up to 25% (McKinsey & Company and Global Fashion Agenda 2021), primarily by minimising the demand for virgin materials.

Eliminate waste and pollution, circulate products and materials, and regenerate nature are the key foundational principles of a circular economy according to the Ellen Macarthur Foundation. In a truly circular system, the concept of "waste" barely exists: what one system discards, is a resource for another. Certain materials can be recycled and remanufactured multiple times, others can be safely composted returning nutrients to the earth. The *Butterfly Diagram* (Figure 1) distinguishes between "biological" materials and "technical" materials. Materials of renewable origin should enter the biological cycle and are intended to be cascaded through systems like composting, anaerobic digestion, or extraction of biochemical feedstock. Finite materials are part of the technical cycle, whereas their lifecycle can be prolonged through different methods, from sharing, reusing, redistributing, remanufacturing, refurbishing, and recycling.

A logical conclusion of these theoretical principles is that products should be designed to belong to the biological cycle or the technical one. When an object is manufactured with materials belonging to both cycles, an additional step should be planned, concerning the separation of the materials it is made of, so that they can subsequently circulate in their respective cycles.

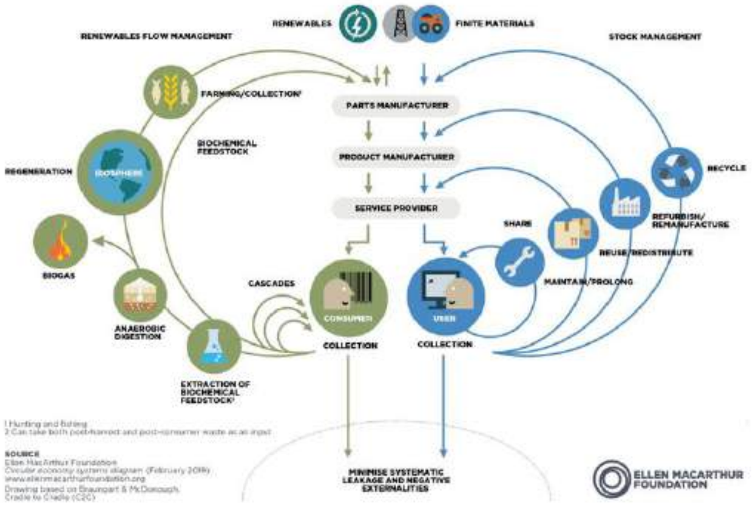

Figure 1: The Butterfly Diagram illustrating biological and technical cycles in a circular economy (Ellen MacArthur Foundation, 2019).

Material end-of-life pathways

The final stage in the life cycle of materials which are compatible with the biosphere is biodegradation or composting. A material is biodegradable if it can be broken down by natural microorganisms into water, methane, or carbon dioxide. However, this process is dependent on both the material's intrinsic properties, such as fibre type and chemical treatments, and the external environmental conditions in which decomposition occurs. Cold temperatures, low humidity, limited oxygen, and nutrient-poor settings can significantly slow or prevent degradation (Sommer, Skilbeck & Blackburn 2024).

Compostable materials are those that biodegrade in a controlled, nutrient-rich environment, producing compost suitable for use as fertiliser. While all compostable materials are biodegradable, not all biodegradable materials meet compostability criteria. According to EU standard EN 13432:2002, compostable materials must degrade by at least 90% within six months and must not impair the quality of the compost produced (Centrocot 2021).

So far, composting trials have focused on mono-material yarns and fabrics. Further research is needed to evaluate how material blends or certain finishing treatments affect decomposition rates and compost quality (Manteco Spa 2021).

After the materials belonging to the technical cycle have undergone multiple cycles for reuse, repair, remanufacturing, they should be prepared for recycling. The main recycling technologies used for textile are mechanical and chemical.

In mechanical recycling, textiles are sorted by fibre type and colour, then shredded and spun into new yarn. Mechanical recycling is a well-established, relatively low-cost technology which works well with different fibre types.

Chemical recycling breaks down the fibres to their molecular level, which are the re-polymerised to produce new fibres. It is a newer technology, with different entities that are developing their own methods and solvents.

Pre-consumer textiles are generally preferred for mechanical recycling, as post-consumer garments often present challenges related to unknown fibre composition and degraded material quality. Materials should be as "pure" as possible, both in terms of fibre composition and chemical treatments. Depending on the technology used, some chemical recycling plants can process blends of polycotton up to a certain percentage and are more tolerant of certain dyes and finishes. Elements such as decorative metallic yarns, buttons, zippers, heavy embellishments require manual removal before recycling. Elastane is a challenge for most recycling plants: when >5% it makes recycling, both mechanical and chemical, impossible (Choudhury, Tsianou & Alexandridis 2024).

Current labelling practices and their impact on circular design

The whole system is connected, every decision a designer makes, determines what cycles, if any, the garment will undergo. One of the most critical stages preceding recycling is sorting, which is key in the accurate identification of material composition. The success of both mechanical and chemical recycling technologies relies on this information, as many processes are incompatible with certain fibre blends or finishes.

Textile labelling in the European Union is currently governed by Regulation (EU) No 1007/2011, which mandates that products containing at least 80% by weight of textile fibres must be labelled with their fibre content. Care labels typically include information on size, country of origin, washing instructions, and fibre content. However, their reliability at end-of-life is limited: labels are often faded, removed by users, or simply inaccurate (Circle Economy 2020b).

Emerging technologies such as Near-Infrared Spectroscopy (NIR) offer promising alternatives for automated fibre identification, as they can enhance sorting accuracy without relying on labels. These systems are still under development and not yet widely scaled (Refashion 2025).

The limitations of existing labelling systems, along with the widespread use of fibre blends, coatings, embellishments, and complex constructions, are key factors behind the fact that only around 1% of clothing is currently recycled in a closed-loop, textile-to-textile process (Ellen MacArthur Foundation 2024).

To enable a circular textile system, several material and informational criteria must be met. These include:

- Preference for mono-materials wherever possible
- Design for disassembly (e.g., easily removable fasteners)
- Minimisation of chemical finishes or coatings that hinder recycling
- Transparent and accurate composition on the label

Methodology

Research through Design

Design can be understood as a means of inquiry, a way of formulating and refining questions through making. When embedded within the design process, design research allows for the emergence of new and unanticipated questions, expanding the scope beyond the boundaries of a predefined problem (Zimmerman 2003). As Zimmerman, Forlizzi and Evenson (2007) describe, these emergent questions are often answered through iterative cycles of design activity, including experimentation and play. This methodology, known as Research through Design (RtD), has been defined as a “practice-based inquiry that generates transferrable knowledge” (Durrant et al. 2017, p. 3).

Given the exploratory nature of the study, a Research through Design strategy was adopted. The outcome is a product prototype, an artefact that serves to explore the conditions which enable or limit circular design within fashion policy and practice.

Data collection methods

The research process was iterative in nature, both in terms of data collection and analysis. Thematic analysis was employed to interpret findings progressively, allowing each stage of research to inform the next. This process contributed to the gradual development of insights and theory grounded in practice.

Primary data was collected through semi-structured interviews with six experts in fields such as regenerative agriculture, circular design, cradle-to-cradle certification, and sock manufacturing.

Secondary data was initially gathered through a review of texts, including organisational websites, industry reports, market databases, journal articles, and books. This helped identify the research gap and inform the formulation of the initial research questions. Secondary data collection continued throughout the project to support the development of the prototype. In addition, the project included a material culture study of existing products. Analysing socks from various brands provided valuable insights that informed the design choices.

Findings of the study and implications

Design intervention: developing a circular sock prototype

Socks are a highly functional yet frequently overlooked item within our wardrobes. Due to their constant use and exposure to friction, they are particularly prone to wear and tear, often developing holes or becoming overly worn in a relatively short time. As a result, socks are commonly perceived as low-value garments, cheap to replace and rarely repaired. Despite the possibility of mending them, few individuals are willing to invest the time and effort required to hand-repair an item considered so disposable.

This disposability contributes significantly to textile waste. Most commercially available socks are not biodegradable nor recyclable, meaning that once discarded, they are likely to end up in landfills or be incinerated.

Considering these issues, the researcher chose to develop a sock prototype that aligns with the biological cycle of the Ellen MacArthur Foundation's Butterfly Diagram. Unlike technical materials, which tend to retain moisture and create a damp environment against the skin, natural fibres such as cotton are breathable and absorbent, promoting greater comfort and hygiene during wear. While some synthetics are engineered to wick moisture, they often require chemical treatments or blends that further complicate recyclability and biodegradability.

From a lifecycle perspective, synthetic fibres also pose a challenge. Although they can undergo mechanical or chemical recycling, current technologies do not support infinite recycling cycles, as fibre quality degrades over time. Moreover, while recycling is often seen as less impactful than producing virgin fibres, this is not universally the case: recent studies have shown that, for materials such as polyester or cotton, recycled fibres can in some instances result in higher environmental impacts in specific categories due to energy-intensive processing (Abagnato, Rigamonti & Grosso 2024). For low-durability items such as socks, whose short lifespan limits opportunities for reuse or extended use, the environmental cost of multiple recycling cycles may outweigh the benefits.

For these reasons, cotton was selected as the primary material for the prototype. Cotton offers a balance of functional performance and environmental responsibility: it is naturally breathable, biodegradable, and mechanically recyclable. While recycled cotton fibres do lose strength over time, they can still undergo several reuse cycles and eventually return safely to the biosphere through composting. This makes cotton particularly suitable for low-durability items like socks, where both comfort in use and end-of-life are essential considerations.

Textile label regulations and circularity barriers

The widespread availability of socks labelled as 100% cotton might suggest that the market already offers products compatible with circular design principles. However, further investigation reveals that this assumption is misleading. A closer reading of EU Regulation No. 1007/2011 exposes a significant loophole: certain fibres do not need to be declared on the garment label if they are used in specific structural components. These include:

- Visible, decorative fibres up to 7% of total weight
- Elastic yarns used in the cuff
- Reinforcement and stiffening yarns in the toe and heel (often synthetics)

Figure 2 provides a visual representation of the areas excluded from mandatory composition disclosure.

Figure 2: Illustration of the rules for labelling sock composition, showing excluded areas (Alice Soncina, 2025).

This lack of transparency has direct consequences for recyclability. While a sock may legally carry a “100% cotton” label, it may still contain synthetic components, such as polyamide or elastane, that reduce its potential for successful mechanical recycling or biological decomposition.

The sock prototype developed in this research project aimed at addressing this issue. Its design prioritises full material disclosure, mono-material construction, and compatibility with both recycling and composting systems. These attributes distinguish it from existing products, which often comply with labelling laws while still failing to meet circularity standards in practice.

The EU Regulation on Textile Labelling governs all textile products placed on the market, providing manufacturers with guidelines on which components of a garment must be declared in the product’s composition. However, these labelling requirements contain exceptions that lead to discrepancies between what is stated and what is present in the product. This issue is particularly critical in the case of socks, as the components exempt from disclosure, such as the heel, toe, and cuff, often comprise a significant portion of the overall product, thereby undermining the transparency of its actual material composition.

The prototype developed through this research directly addresses these shortcomings, challenging both the material construction of socks and the regulatory framework under which they are produced. It demonstrates that achieving true circularity in everyday products like socks is not only possible, but increasingly necessary as part of a broader shift towards circular fashion systems.

Supply chain complexity and data integrity challenges

Accurate fibre composition in labels is essential for enabling efficient textile sorting and recycling. However, recent studies highlight significant discrepancies between declared and actual material content. A study by Circle Economy (2020a) analysed a sample of 10,901 garments, comparing their labels to the results of Fibersort, an automated sorting technology that uses Near-Infrared Spectroscopy (NIR) to identify fibre content. The findings revealed that 77% of garments composed of a single material were labelled accurately, while for blended textiles the percentage of accuracy was down to 41%. 11% of the cotton-polyester blends contained more cotton than indicated on the label. But for around ⅓ of the cotton-rich cotton-polyester garments analysed, the cotton content claimed on the label was overstated compared to the reality of the composition.

These inaccuracies highlight a critical problem: fibre composition data is often imprecise or lost as garments move through the supply chain. The textile supply chain is long and fragmented, involving multiple stakeholders from fibre producers and yarn manufacturers to garment assemblers and retailers. Each stage can dilute the reliability of composition data, especially when information is transferred indirectly through intermediaries (European Parliamentary Research Service 2024a).

For instance, brands often obtain data from Tier 1 suppliers, the factories responsible for garment assembly, while information on earlier stages such as yarn production, dyeing, or fibre cultivation is far harder to trace. This lack of transparency makes it difficult to verify fibre origin, content, or processing claims. “Every cotton fabric and piece of apparel that we use today is constructed from millions of small fibres. The fabric may be labelled as 100% cotton, or a cotton-blend, or a manufacturer might claim to have woven fabric from yarn of a specified count, or to have produced a product through a specific process, or in a particular country, or from a certain species or a specific cotton variety. Currently, it is very difficult to objectively verify such claims” (Das et al., 2017, p.5).

From physical labels to digital passports

Recyclers involved in a study conducted by Circle Economy (2020a) raised concerns regarding the role of labels as contaminants in textile-to-textile recycling processes. Labels are often composed of materials that are incompatible with the garments to which they are attached, especially in mechanical recycling, where a highly pure input feedstock is essential. As a result, labels must be manually removed during the sorting phase, introducing additional labour and complexity.

In many cases, labels are missing altogether, cut off by users or rendered illegible due to multiple wash cycles. In the case of socks, the labels are usually cardboard hangtags or wraps attached to the product, which have to be removed by the user. Even when present and legible, labels may be inaccurate, reflecting inconsistencies between declared and actual fibre content. Thus, although created to promote transparency and product care, the current labelling system has proven to be insufficiently reliable for supporting end-of-life recycling (European Economic and Social Committee 2023).

The Digital Product Passport (DPP) is part of the EU EcoDesign for Sustainable Products Regulation (ESPR), which aims to enhance traceability, circularity, and transparency throughout the entire supply chain of fashion products. Specific rules for the textile sector are currently under development, with phased industry rollout planned between 2027 and 2030 (Carbonfact 2024).

The DPP is expected to encompass up to sixteen categories of information (European Parliamentary Research Service 2024b), which include detailed product descriptions, precise material composition, and comprehensive supply chain data. Circularity-related attributes, such as recycled content, repairability, and take-back schemes, will also be included, along with data on hazardous substances and regulatory compliance. Collectively, these data points could have an impact on design choices and how the garments are handled throughout their lifecycle.

Conclusion

By adopting a Research through Design approach, the project used the sock as a lens through which to investigate broader systemic issues and potentials within the fashion industry. The resulting prototype of a recyclable and compostable sock is not only a practical design outcome but also a critical artefact that questions outdated conventions in sock manufacturing, especially regarding material purity, repairability, and label transparency.

Through expert interviews and material investigations, the project identified that current care label systems, frequently inaccurate, incomplete, or incompatible with recycling infrastructure, pose a substantial obstacle to circularity, particularly for items like socks. While design for longevity is widely promoted in sustainable fashion, socks present a unique challenge: due to their intimate use and wear, they are often discarded at the first sign of damage. This makes it even more urgent to develop socks that are designed for disassembly, recycling, or safe biodegradation.

Upcoming changes to the EU textile labelling regulation may help resolve some of these issues. Proposals to mandate disclosure of chemical treatments and fibre content with greater accuracy would support recyclability (European Economic and Social Committee 2023). However, during the transitional period textile recyclers will continue to handle garments with limited or unreliable data.

The implementation of the Digital Product Passport under the EcoDesign for Sustainable Products Regulation is expected to further improve traceability and end-of-life management for garments, including socks (Legardeur & Ospital 2024). The DPP promises to deliver structured, verifiable data about material composition, chemical use, and circular attributes. This shift from physical labels to digital, machine-readable information could be particularly impactful for small textile items like socks, which are often overlooked.

As Webster (2017, p. 161) notes, “a designer is an emerging synthesis of artist, inventor, objective economist and evolutionary strategist.”. This project affirms that socks are a valuable space for design-led experimentation and systemic change. By embedding recyclability, compostability, and traceability from the start, socks can become fully integrated into circular material flows, rather than contributing to the waste generated by fashion.

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Developing a Circular PSS: Insights on the Adaptation of Regulations Through a Reusable Packaging Case Study at an Airport

Elisabeth Tschavgova

PhD Researcher

Delft University of Technology

The Netherlands

Sonja van Dam

Assistant Professor in Circular Product Design & Transitions

Delft University of Technology

Netherlands

Conny Bakker

Professor Design for Sustainability and Circular Economy

Delft University of Technology

The Netherlands

Jo M.L. van Engelen

Professor Emeritus

Delft University of Technology/University of Groningen

The Netherlands

Rita Jonyer

Circular Economy at Avinor

Avinor

Norway

Anette Rognan

Circular Economy at Avinor

Avinor

Norway

Abstract

Upcoming packaging regulations challenge the linear economy, necessitating behavioral changes among employees, consumers, and businesses. This research aims to identify enablers and challenges of developing a product-service system (PSS) to replace disposable takeaway packaging, focusing on behavioural change in a complex environment.

A case study was conducted at a Norwegian airport, specifically examining the development and implementation of a reusable bowl PSS.

Waste streams were analysed through co-creation workshops and waste composition analyses over two years. This resulted in a one-month pilot PSS at the airport's D-Gate, which was evaluated though qualitative and quantitative data.

Findings reveal that passenger and employee engagement are interdependent and influenced by the airport environment. The study suggests solutions like green procurement, phased implementation, increased promotion, and the development of PSS that are visible, convenient, and frictionless. It highlights the need for coordination between government incentives and startup innovations to effectively advance reusable PSS.

Introduction

Given the urgency of the climate crisis, the European Commission has identified circular economy (CE) as a key priority for achieving sustainability (European Commission, 2018). Transitioning to a CE is regarded as an effective strategy for reducing the negative environmental impact of organizations across various sectors (Pizzi et al., 2022). In response, Norwegian airports, as part of the Avinor group, are actively working towards circularity (Avinor, 2023), driven by both internal sustainability goals and external regulations. One regulation relevant for this transition is the upcoming EU Packaging and Packaging Waste Regulation (PPWR), which aims to minimize packaging waste while reducing reliance on primary raw materials, enhancing resource efficiency, and fostering a sustainable, competitive economy. By aligning with the PPWR, Norwegian airports seek to explore the integration of CE principles into reusable takeaway packaging.

The objective of this research is to identify the enablers and challenges of developing a successful circular product-service system (PSS) to replace disposable takeaway packaging, with a focus on behavioral change in a complex environment. To achieve this, a case study was conducted at a Norwegian airport, which centered on the development and implementation of a PSS using reusable bowls. This research was guided by two key questions:

> RQ1: What are the key enablers and challenges of in implementation and development of a reusable bowl PSS within the airport context?
>
> RQ2: What broader insights and lessons can be derived from this case study regarding interventions that advance green transitions in complex environments like airports

Background

Airports are progressively adopting CE principles (Van Der Tuin-Rademaker et al., 2024), yet they are facing increasing waste due to rising passenger volumes (AITA, 2024). Avinor's focus on reusable packaging challenges the predominant linear model of take-make-dispose. This circular transition requires a systemic approach (Guzzo et al., 2022), that engages various stakeholders, including employees, passengers, and industry partners. However, these stakeholders often work in silos, leading to inefficiencies and hindering the adoption of CE concepts (Van Der Tuin-Rademaker et al., 2024).

Literature on reusable packaging research indicates a gap of multidisciplinary perspectives, as quantitative methods are emphasised while lacking insights from social sciences and service design (Bradley & Corsini; 2023) based on empirical cases (Tenhunen-Lunkka et al. 2024). To advance the field, a comprehensive multi-stakeholder approach involving retailers, manufacturers, logistics companies, policymakers, non-profits, and consumers is necessary (Bradley and Corsini, 2023).

Consequently, this research focuses on an empirical case study exploring enablers and challenges in the development of a reusable takeaway PSS considering the diverse airport stakeholder perspectives. Systemic design (SD), which integrates systems thinking and design (Bijl-Brouwer and Malcolm, 2020), is considered promising to navigate airport complexity due its holistic and co-creative nature (Jones, 2018).

Methodology

The case study follows an action research approach (Price et al., 2021) with the plan-act-observe–reflect-cycle (Interaction Design, 2015), as shown in figure 1.

Figure 1: Action research process embedded in case study

Exploration airport

Co-creative workshops with airport representatives and a waste composition analysis were conducted to understand the current airport waste management system. This included mapping material flows, examining resource stream compositions by weight and volume, and verifying treatment processes following the BCAM approach (Van Der Tuin-Rademaker et al., 2024). These activities provided an overview of the waste generated, particularly on the residual waste stream, which is the largest stream and incinerated for energy recovery as it is not recyclable. Various scoping sessions and student projects explored sustainable interventions targeting this waste stream. One project developed over six months introduced a reusable takeaway packaging system called "Green Circles" (Falcón, 2024) targeting single-use-takeaway packaging items, as these are among the most commonly found items in the residual waste stream.

Pilot development

A single case study approach (Yin, 2014) was used to test "Green Circles" at Oslo Airport, focusing on a fully operational infrastructure for reusable packaging over one month at the international D-Gate with two restaurants. The development involved collaboration with Avinor's circularity team and external stakeholders, including providers for the smart return machines, payment system, and reusable bowls. The pilot included QR-coded reusable bowls, a Point-of-Sale (POS) system, smart return machines, a centralized dishwashing service and promotional materials (Figure 2).

Figure 2: 2.a: Promotion material and reusable bowl; 2.b: Smart return machine; 2.c: Scanning QR code of reusable bowl by employee to activate POS; 2.d: Customer tapping with card at POS to activate the deposit-free borrowing system (Photos @Rita Jonyer)

Passengers could opt for meals in reusable bowls from participating restaurants. At checkout, a "tap-and-reuse" approach allowed passengers to link their bank card it to the borrowed bowl without any deposit. If the bowl was not returned within a week, a fine of 70 NOK would be deducted. Bowls could be returned at six designated smart return machines located at the international gates D and E, where they would be collected for cleaning and redistribution (Figure 3).

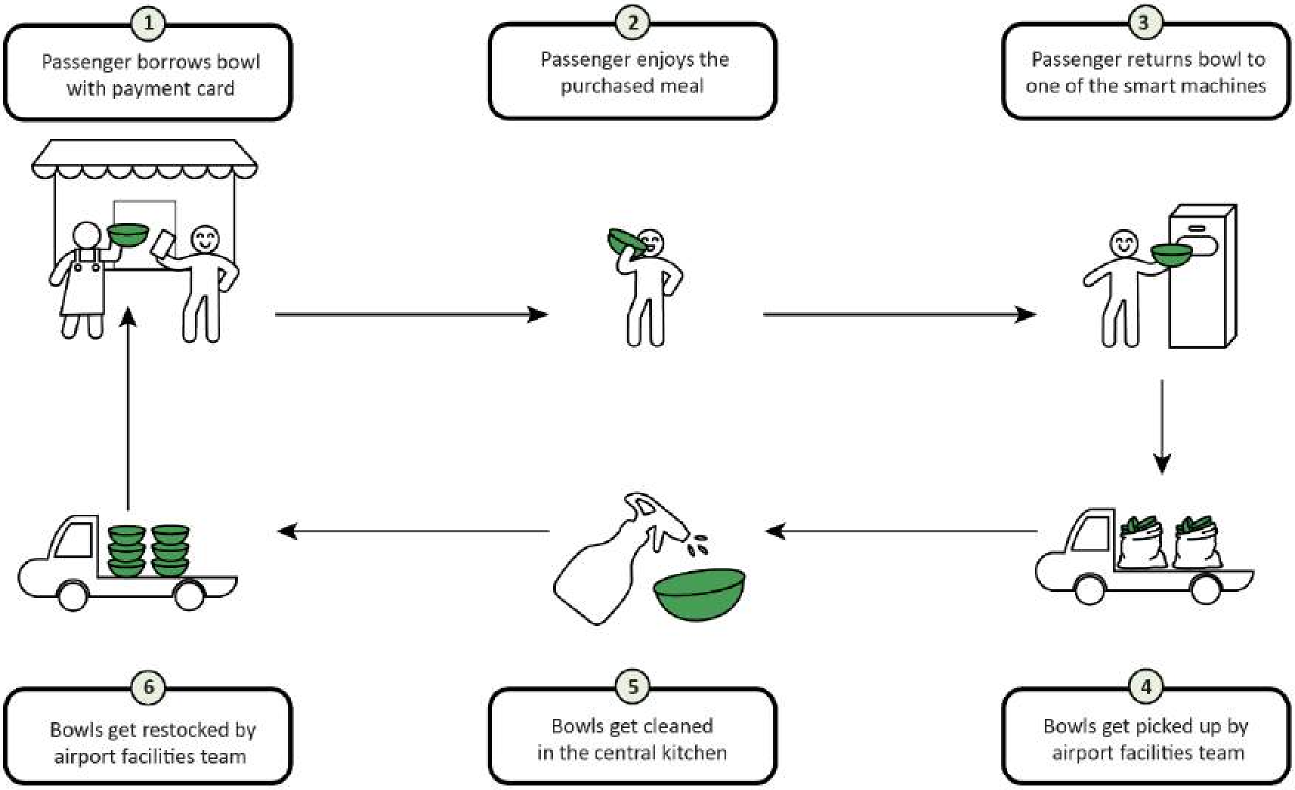

Figure 3: Process of the pilot: Steps 1-3 show the front end of the bowl borrowing process and steps 4-7 show the backend in terms of pick up, cleaning and redistribution of the bowls

Pilot execution

This study employed a mixed-methods approach to capture the different stakeholder perspectives. Quantitative data was collected though passengers surveys (n=59) at the participating restaurants, focusing on their awareness and choices regarding the reusable packaging option. Qualitative data, which included interviews (n=9) with various stakeholders like employees and industry experts, provided insights on the PSS. Additionally, on-site observations at key locations, such as restaurants, smart return machines, and seating areas, along with informal conversations with staff and passengers, were conducted. A field diary documented observations and insights throughout the pilot.

Analytical framework

The final phase of the research involved synthesizing data to extract key insights on the development and implementation of a reusable packaging PSS in the airport environment.

An analysis framework was created based on research questions to structure the findings around 8 key themes. For RQ1, internal stakeholders frequently discussed "communication and information flow" and "consumer engagement" to ensure viability and functionality of the PSS, while for external stakeholders who provided the return machines and POS highlighted "airport contextual issues" and "employee engagement" as relevant topics. RQ2 themes, identified through industry expert interviews, included "Broader System Actors" and "Regulations & Policies" as relevant for reusable packaging. Subsequent coding and clustering of relevant quotes led to the final topics: "Feasibility & Implementation" and "Scalability".

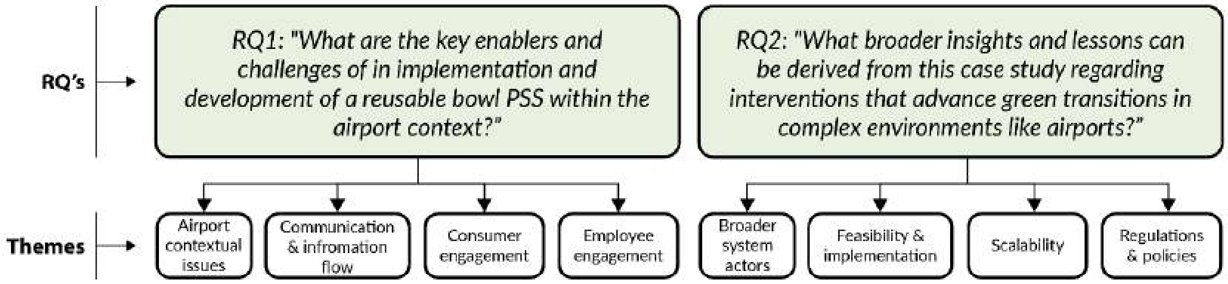

Figure 4: Analytical framework

Results

Before discussing the findings of the case study, it is essential to understand the unique challenges of implementing a reusable packaging PSS within the airport environment, which is shaped by its high-pressure and transient nature. Unlike traditional food service settings, airports deal with a constantly changing flow of passengers, who often lack familiarity with reusable packaging and may not return for future engagement, making it difficult to create lasting behavioural change. Additionally, the stress passengers experience during travel and the demands on employees during peak hours complicate efforts to promote reusable options, next to language and cultural barriers.

Borrow rate

The pilot resulted in a low borrow rate of 35 reusable bowls within a month, facing several technical challenges such as internet connectivity issues, malfunctioning POS devices, currency errors, and smart return machines being disconnected by passengers. However, these challnges were fixable during the pilot or in the future, and not the primary causes of the low borrow rate. Instead, factors such as low awareness and engagement, operational and logistical barriers, and contextual issues were identified as the leading reasons for the low borrow rate.

Low awareness and engagement were identified, as the survey revealed that 49% of the interviewed passengers were unaware of the reusable alternative, despite promotional materials. Employee interviews confirmed limited promotion due to language challenges, competing work priorities, the additional workload required to explain the reusable bowl, and insufficient knowledge. Additionally, employees often did not ask passengers about their intended dining location and defaulted to using disposable packaging even though, 66% of passengers surveyed planned to eat at the restaurant, which would require serving meals on ceramic plates instead of disposable takeaway packaging.

Next to the operational barriers due to technical issues with the payment system and return machines, logistical barriers have been identified. The survey indicated that 44% of passengers received meals pre-packed in disposable containers, which stemmed from logistical processes in airport food production as discovered by observations.

Finally, contextual constrains due to the transient and high-pressure airport environment posed unique challenges in the implementation of the PSS. In informal conversation passengers expressed reluctance to use the reusable bowl due to stress, time constraints, and uncertainty about navigating the process in an unfamiliar environment. Even the willingness and ability of environmentally conscious employees to promote the bowls was reduced due to the pressure of explaining the bowl during peak hours, limited knowledge about the system, as well as negative interactions with stressed passengers.

Key insights analytical framework

To synthesise the findings from the case study, all insights got mapped into the eight analytical themes of figure 4 and summarized.

Airport Contextual Issues: The airport environment shows unique barriers such as security restrictions, spatial limitations, language barriers, diversity in passengers and time pressure for passengers and employees. These barriers contribute to the transient and stressful nature of the airport's open-loop system, putting it in less suited position to lead the transition to reusable packaging.

Communication and information flow: Clear and consistent communication was vital for engaging employees and passengers during the pilot. However, fluctuating staff numbers over time and an overall high staff number (20-60 per restaurant) made it difficult to ensure that all employees are well-informed. Increased customer awareness regarding reusable bowls through larger scale campaigns, additional employee training, and accessible information across all stakeholders were suggested to improve communication strategies.

Entanglement of "Consumer engagement" and "Employee engagement": Without active promotion from employees, the bowls remained largely invisible to passengers. This highlights again the significance of employee engagement across the whole PSS. Simplifying employee touchpoints and integrating system information into staff training next to enhanced passenger promotion to simultaneously reduce promotional workload at employees was proposed to reduce friction and encourage participation.

Broader system actors: Expert interviews emphasized that internal and external stakeholders are essential for aligning incentives, standardizing infrastructure, and establishing shared ownership of the reusable packaging system. This becomes even more relevant when scaling beyond the airport, as no single actor, can drive this transition alone. Instead, collective action from a consortium of brands, retailers, and public bodies is necessary.

Feasibility & implementation: The pilot revealed that implementing reusable packaging in an airport context is constrained by lack of stakeholder engagement, internal logistics and PSS readiness. Challenges stemmed from established operational routines, such as pre-packed food in disposable packaging, as well as technical issues with the emerging technologies utilized during the pilot. These findings highlight the importance of robust infrastructure, regulatory alignment, and a context-specific design.

Scalability: Scalability of reusable packaging at the airport depends on standardization, regulation, and ownership. Standardization across product types, infrastructure, and return processes reduces friction and enables broader adoption, while allowing flexibility for individual vendors. National and EU regulatory frameworks can position reuse as the default option, enhancing its financial viability and creating a self-reinforcing loop of standardization and scalability. Ownership needs to align with system scale, while airports may manage infrastructure locally, broader expansion requires government or consortium-led models.

Policy & Regulations: Expert interviews highlighted that policies encourage infrastructure development and standardization, making reusable packaging feasible for businesses to adopt. Further, regulations associated with financial penalties or rewards can motivate wider system stakeholder to prioritize and enforce reuse, such as the bottle deposit system in Germany.

Discussion

Based on the insights from the case study, the discussion can be organized into five important lessons for those involved in developing and implementing reusable packaging PSS to advance circular transitions in a complex environment like an airport:

Importance of Contextual Factors: This case study underscores the significance of contextual factors in influencing sustainable behaviour (Ertz et al., 2017). Within the airport environment, factors such as time pressure and stress significantly impacted the engagement of passengers and employees. This stress is consistent with research indicating that consumers increasingly perceive time as scarce (Ertz et al., 2017), a perception potentially amplified in the airport setting. The concept of prosumption (Ritzer and Jurgenson, 2010) is relevant here, as consumers now undertake tasks previously managed by employees, such as digital check-ins and ordering. These activities transfer responsibility and cognitive load to consumers, heightening their desire for speed, ease, and convenience. Consequently, disposable packaging often becomes the preferred choice, while reusable alternatives may be seen as an additional burden. This finding highlights the necessity for reusable systems to require minimal cognitive effort and integrate seamlessly into existing service flows for both consumers and employees, particularly in high-stress environments like airports.

Interdependence of Stakeholders: The interdependence between passenger and employee engagement highlights the need for strategies that address both groups. Effective communication, training, and motivation of employees are crucial. Additionally, broader stakeholder engagement is essential, as airports alone cannot lead such transitions. Top-down interventions, such as legislation and fiscal incentives, are required to reshape market conditions, working in synergy with bottom-up initiatives in environments like airports. These efforts can drive innovation through new technologies and business models (Geels, 2011; Guzzo et al., 2022).

Systemic Design Approach: Implementing reusable packaging in an airport context requires a systemic approach that considers technological, behavioural, and institutional factors. A holistic and co-creative design process can help navigate these complexities and design a PSS in consideration of the wider ecosystem it aims to be embedded in as well as impact. The pilot showcased the value of a SD approach in addressing the intricacies of a highly regulated, multi-stakeholder environment like an airport. As Jones, (2014) argues, SD is particularly well-suited to address "wicked problems" in sustainability where actors, goals, and systems co-evolve. In this study, SD enabled iterative, co-creative processes involving participants across multiple airport departments, hierarchical levels, and external stakeholders in collaboratively designing a PSS pilot, to gather insights for the development and implemtation for resuable packaing PSS .

Role of Regulation and Policy: Supportive regulations and policies from higher levels, such as the PPWR, can create top-down pressures and opportunities for standardization. This helps align efforts across the value chain and normalizes circular practices. Additionally, context-based regulations specific to airports, like the green procurement policies that charge extra for takeaway containers, can discourage the use of disposable items and promote reusable containers for pre-prepared food. These measures can further reinforce the implementation of reusable packaging systems. The question about ownership may arise depending on the scale of the PSS. Effective governance for micro-level environments, such as airports, will depend on their specific context, while broader scaling may require hybrid public-private governance structures with clear accountability, regulations, and lifecycle oversight.

Value of Pilot Studies: Pilot studies in complex environments like airports can serve as testing grounds to experiment, iterate, and inform systemic change, as well as provide valuable insights into the feasibility and adaptability of PSS in real-world settings. Airports, as encapsulated ecosystems, can serve as a testing ground to experiment, iterate, and explore PSS, as done in this case study.

Next Steps and Implications

The pilot study not only highlighted the challenges inherent in the airport context but also identified feasible strategies to address them. Moving forward, reusable packaging systems should be designed with careful consideration of contextual constraints, ensuring they are visible, convenient, and frictionless. Concurrently, disposable alternatives should be made less accessible or attractive. As Ertz et al. (2017) argue, creating environments that facilitate reuse and discourage disposables shifts perceived utility toward sustainable choices. When passengers perceive reusables as the default or less of a hassle, they are more motivated to choose them.

Next steps at the airport in the implementation of a resusable packaging PSS would involve a phased approach to promote reusable bowls, starting with employees to establish internal norms and behavioral routines. This closed-loop system allows for manageable integration before extending the program to domestic flights, where travelers are already familiar with reuse practices such as deposit-return schemes. Once restaurant employees have integrated reusable bowls into their workflow, additional reusable packaging, such as coffee-to-go cups, can be introduced. This expansion will build on an already functional system and promote a broader reuse initiative, leading to full airport-wide implementation, including international flights, as reuse practices become more visible and normalized.

Limitations

This study offers context-specific insights into reusable packaging adoption within an airport environment. Since it was scoped to study the behavioral effects of the PSS intervention, it by no means can be a proposal for new business models or quantifiable CE implications. Further research is welcome to build on the presented findings and focus on different contexts and more specific design interventions, eventually resulting in CE advancements and new business propositions.

Conclusion

This empirical case study provides valuable lessons for those involved in developing and implementing reusable packaging PSS to advance circular transitions in a complex environment like an airport. The study emphasizes the need for a SD to effectively promote sustainable innovations.

At the case-specific level, the findings highlight that passenger and employee engagement are interdependent and strongly influenced by the airport environment. Airport specific constraints such as stress, time scarcity, spatial limitations, and diversity in cultures coming together challenged the implementation of reusable bowls. Scaling a reusable packaging concept would be easier in an another less demanding and restricted environment than an airport. Nonetheless, the pilot also revealed feasible interventions, such as green procurement, phased implementation, increased promotion and the development of PSS that are visible, convenient, and frictionless for passangers and employees. Beyond the pilot, broader learnings point to the need for top-down and bottom-up alignment, such as governments providing financial incentives for reusable packaging though legislation and start-ups developing innovations in addressing these.

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Developing a Circular Design Approach: Towards Truly Sustainably Stronger Solutions

Aino Vepsäläinen

Chief Specialist

LAB University of Applied Sciences

Institute of Design and Fine Arts

Finland

Noora Nylander

Senior Lecturer

LAB University of Applied Sciences

Institute of Design and Fine Arts

Finland

Introduction

The environmental crisis is accelerating across interconnected scales, with climate change and biodiversity loss reaching critical thresholds. The past decade has been the warmest on record, and 2024 was reported as the first full year with global mean temperatures exceeding 1.5 °C above pre-industrial levels (WMO 2025). At the same time, biodiversity continues to decline rapidly. According to WWF's Living Planet Report 2024, there has been a 73% drop in vertebrate populations between 1970 and 2020.

Human activity has already exceeded seven of the nine planetary boundaries, including those related to climate change, biodiversity loss, land use, freshwater consumption, nutrient cycles, novel entities, and ocean acidification (Rockström et al., 2009; Richardson et al., 2023). Crossing these boundaries risks triggering irreversible ecological changes and threatens the stability of Earth's systems (Richardson et al., 2023).

To ensure a livable planet for future generations, coordinated action across all sectors is essential. Addressing these challenges requires not only systemic policy shifts but also innovative and creative approaches that embrace new perspectives.

In response to these urgent challenges, this study investigates the role of designers in advancing strong sustainability. The research was conducted within the Estonian-Finnish Erasmus+ project called Circular Design Training Program, a collaboration between the Estonian Design Centre and LAB University of Applied Sciences. It explores the competencies needed to support circular and regenerative solutions and considers whether current design practices align with the principles of strong sustainability.

The central research question is: What skills are essential for designers, and how can we harness their potential in creating sustainable solutions and contributing to the emerging paradigm of sustainable and regenerative growth?

From weak to strong sustainability

Given the scale and urgency of the environmental crisis, addressing these complex challenges requires the active involvement of various professional fields. Designers hold a unique position in shaping sustainable futures through their influence on products, services, and systems that impact both society and the environment. However, despite their critical role, many designers currently lack access to updated skills and knowledge necessary to respond effectively to the demands of the green transition (Kulka & Drew 2024, 10).

This study, conducted as part of a collaborative Estonian-Finnish Erasmus+ project, explores the competencies designers need to effectively address global challenges, such as climate change and biodiversity loss, in accordance with the principles of strong sustainability. Additionally, the study investigates whether current methods and tools predominantly support weak rather than strong sustainability in design practice. This raises the question: What is the significance and relevance of existing design practices and frameworks in this context?

The paper begins by examining the role that design can and should play in addressing the sustainability crisis. It then introduces the concepts of weak and strong sustainability, followed by an overview of the Erasmus+ project *Circular Design Training Program*. Finally, the paper discusses how designers' skills and capabilities should be developed to meet the emerging demands of sustainability. This article also introduces an educational framework developed within the project, aimed at addressing the identified skills gap.

Designed specifically for practicing designers, the framework aims to support the development of capabilities needed to influence the creation of circular, sustainable, and regenerative solutions. By developing a framework that fosters strong sustainability competencies, the initiative seeks to strengthen, in the long term, the role of designers as active agents of change in the transition toward a more sustainable and ecologically sound future.

The sustainability crisis challenges societies, industries, and the design field to critically reassess their approaches and practices. Design for sustainability has become a central paradigm in this context, as designers are increasingly expected to deliver solutions that not only minimise harm but also foster regeneration and create entirely new ways of addressing complex challenges. (LAB University of Applied Sciences & Estonian Design Centre, 2025a).

Design for Sustainability (DfS) has evolved from a narrow product-level/eco-efficiency approach, or so-called `weak sustainability` which mainly means reducing harm in existing systems, towards a systems-level, socio-technical change approach (Ceschin & Gaziulusoy 2016). This approach, known as `strong sustainability` requires a change in how societal needs are met (Ceschin & Gaziulusoy 2016). `Weak sustainability' sees nature and produced capital as unchanging, while `strong sustainability` seeks to preserve nature's capacity intact and respect it as more than just a commodity (Salonen et al. 2025, p 5). This shift is moving the design industry away from incremental improvements toward promoting profound systemic innovations and changes (Ceschin & Gaziulusoy 2016).

Rockström et al. (2009) argue that sustainability necessitates radical change because environmental limits, specifically planetary boundaries, are being exceeded, and this is one of the primary reasons why design skills must shift towards a systemic approach. According to Salonen et al. 2025, p. 3, the paradigm is changing, and companies are no longer merely economic actors but creators of thriving socio-ecological systems that challenge the traditional role of profit maximisation. The transition to strong sustainability, which is described similarly as regenerative development, is changing the nature of business (and design) professions, as it requires systemic, positive contributions to socio-ecological systems, not just improvements in efficiency (Salonen et al. 2025).

Ceschin & Gaziulusoy 2016 state that although measures to improve eco-design and efficiency yielded results, they soon became marginal and costly and were overtaken by growth in consumption. As a result, previous approaches (weak sustainability) were insufficient to address the scale of environmental and societal challenges. The design sector therefore needs skills and innovation models that combine not only technology but also social, cultural, and institutional changes. Salonen et al. 2025 propose regeneration as a response to this insufficiency, with the aim of going beyond sustainable development towards a positive net impact and systemic recovery.
This approach of rethinking a design practice through a strong sustainability lens served as the conceptual foundation for the development work, which aimed to explore new paths for advancing circular and sustainable design education, thereby supporting professional designers in their professional growth and the enhancement of their competence capital.

Co-creating a circular design training framework

This section presents a case study in which a framework for a training model was developed through an Estonian-Finnish collaborative project. The study examines how designers can acquire sustainable design principles through practical experience, and how educational content and learning methods should be structured to support this process. The research draws on observations made throughout the project, including project group meetings, internal and stakeholder workshops, and documented outcomes of stakeholder interactions. A qualitative case study approach was applied (Creswell & Poth, 2016).

The motivation for this development work stems from the ongoing sustainability crisis and the urgent need for systemic change across industries to which the design profession is inherently connected. As policy and decision-making frameworks such as those introduced at the EU level continue to guide companies toward sustainability compliance, the demand for new competencies among professionals is increasing. Despite these pressures, a critical gap remains in the skills needed to respond effectively, particularly in the field of design.

The evolving expectations placed on designers, shifting from incremental improvements toward systemic and regenerative solutions, formed the basis for a project aimed at developing an approach and course structure to support designers in building practical skills for implementing sustainable solutions in real-world contexts (Ceschin & Gaziulusoy, 2016; Salonen et al., 2025).

The project team explored openly available circular design courses and methods with the aim of gaining an overall understanding of the current course offerings and complementary resources. This analysis sought to identify existing gaps and recent developments, particularly from the perspective of designers' evolving needs. (LAB University of Applied Sciences & Estonian Design Centre, 2025a.

Key barriers and opportunities related to building sustainable design competencies were explored in a stakeholder workshop held in Tallinn in November 2024. Insights from this workshop laid the foundation for the subsequent development phases.

Figure 1. Stakeholder workshop held by Leyla Acaroglu at the Estonian Design Centre, Tallinn (Ruokamo, 2024)

The course structure was developed using co-design methods in a cross-border setting, combining both face-to-face collaboration and online tools. The process was iterative, with key themes, drivers, and content areas co-created together with project partners and stakeholders.

The finalised training model was presented to professionals and design experts for feedback, which was used to refine its structure and content. The framework was then visualised into an accessible and engaging format, designed to support adoption and adaptation across different educational and professional contexts.

Towards systemic design for sustainable futures

The sustainability crisis, including climate change and the depletion of natural resources, is placing increasing pressure on design practices and competencies. Designers hold a central role in shaping sustainable futures through their influence on products, services, and systems. However, many professionals currently working in the field have had limited opportunities to update their skills to meet today's sustainability demands.

Barriers, enablers, and background research

The project began by mapping existing circular design training materials and simultaneously assessing designers' skills gaps/barriers and opportunities. These activities provided a solid foundation for iterative co-development.

The following list shows main barriers and enablers for integrating circular design thinking into design practice. They are based on the outcomes of the first stakeholder workshop (LAB University of Applied Sciences & Estonian Design Centre, 2025b):

Main barriers to integrate Circular Design into the design process/practice:

- -Lack of knowledge and understanding of circularity, life cycle assessment (LCA), systems thinking, and regulations
- -Lack of transparency and clarity regarding data and expectations -Consumers' limited willingness and ability to navigate information and choices
- -Financial barriers to entering the market
- -Lack of understanding of the value of design overall

Main drivers enabling Circular Design into the design process/practice:

- -Development in articulating the value of design (revolution in the meaning of "designer")
- -Exposing the data and making transparency and accountability the norm (such as data availability through DPP)
- -New business models and approaches to developing design solutions
- -Opportunity for a new field of design or practice approaches that legitimise design

Identifying key barriers and enablers, along with familiarising the project team with existing materials during the initial development phase, provided a vital foundation for recognising gaps in current offerings and guided the direction of the co-development process.

These findings are further supported by recent studies conducted by national design organisations. In 2023, Design Forum Finland, the Finnish national design support organisation, conducted a study aimed at professionals in product and service development, which revealed a strong interest in circular design. Attitudes towards continuing education were generally positive, with nearly 90% of respondents expressing at least some interest in developing their competence, and about one-third showing a high level of interest. Furthermore, the report indicated that although interest in sustainable design and the circular economy is high, the overall level of expertise remains low. (Design Forum Finland 2023). Additionally, the Design Council's report highlights that in the UK, 77% of respondents indicate that the need for green transition skills is increasing, yet only 43% feel they have the capability to meet this demand (Kulka & Drew, 2024, 6).

Shaping the training model

During the review of existing educational materials, it was identified that while many e-learning platforms have helped make circular design principles more accessible, especially in business and sustainability contexts, there is still a lack of in-depth, designer-specific content. Although responsibility has long been part of design thinking, today's overproduction and overconsumption demand a fundamental rethinking and adoption of new design practices. Circular design approaches, which are still largely based on linear product-service systems, fall short in addressing the systemic challenges posed by the current situation. (LAB University of Applied Sciences & Estonian Design Centre, 2025a) Against this backdrop, the project initiated a co-development process to create a training model that supports professional designers in responding to the challenges of climate change, resource scarcity, and the global sustainability crisis.

Beyond engaging representatives from the project organisations, the project team collaborated with experts from multiple disciplines to ensure a broad range of perspectives. This collaborative approach was strengthened through both online and in-person workshops, including a cross-border workshop in Tallinn. Ongoing interactions with external experts and partners, in virtual and physical formats, helped ensure the course content reflected diverse perspectives and remained grounded in professional design practice.

Design thinking and designerly ways of thinking offer perspectives that have not yet been sufficiently utilised in circular economy solutions. Secondly, the project aimed to approach the topic from a systemic perspective that considers the environment and the planet's ecological limits. This was emphasised particularly in the first module.

The second module concentrated on people's perspective, understanding human behaviour and decision-making, user research and influence strategies, as well as designing long-term impact and social wellbeing. The third module focused on business needs and business models with an emphasis on aligning business strategies with sustainability goals and exploring regenerative business models that go beyond traditional value creation.

The final two modules concentrated on the designer's own development and design work. The fourth module explored the designer's specific field, from the perspectives of sustainability and systems thinking.

The fifth module focused on helping designers develop their own design process. While circular design resources do exist, they are often scattered and inconsistent. This module aimed to support participants in synthesising that fragmented knowledge into a coherent, personalised practice through structured guidance and reflection. (LAB University of Applied Sciences & Estonian Design Centre 2025c)

Beyond circular design

The developed course structure was based on the understanding that circular design requires more than technical solutions. It demands a systemic mindset. Throughout the modules, emphasis was placed on the interconnectedness and complexity of systems, the importance of understanding and measuring impact, and the integration of social, cultural, and institutional dimensions into innovation. The importance of understanding human behavior, decision-making, and long-term well-being in order to design meaningful and sustainable change was also highlighted.

Figure 2. Structure of Beyond Circular Design educational framework (Moro, 2025).

Toward the end of the course, the focus shifted to the designer's own field and design process. The aim was to encourage participants to rethink their role, learn from others working in sustainable and circular design, and develop their own approach, rather than applying circularity as it is typically taught in business contexts. By providing tools to navigate this paradigm shift, the course seeks to strengthen designers' roles as agents of change in the sustainability transition.

The course's interactive and participatory learning methods follow the ICAP pedagogical model, which suggests that active and constructive engagement with learning materials enhances deep learning (Chi & Wylie, 2014).

The development process began with the idea of building a circular design training course structure for designers. Along the way, it was realised that circular design has already made significant progress in terms of developed materials, and that many methods and tools already exist. However, due to the accelerating pace of the sustainability transition, it is no longer sufficient to improve linear models with circular measures. What is needed is a transformation that goes beyond circular economy principles, a shift toward a truly systemic approach. For this reason, the course framework was named *Beyond Circular Design*.

At the same time, this reflects the broader transition we must collectively pursue: moving from weak sustainability to strong sustainability. This shift redefines the role of design in shaping regenerative futures.

Conclusion

Many designers still work on solutions that serve the needs and expectations of linear business models. This reflects a legacy of weak sustainability, which focuses primarily on minimising harm within existing systems. However, the challenges we face as a society (and also within companies) are increasingly systemic and complex. Designers have valuable capabilities to address these issues, but to do so effectively, professional competencies must evolve faster.

The core of design holds a unique capability: the ability to envision and develop solutions that do not yet exist, solutions that address systemic and emerging challenges. This perspective aligns with the broader shift from weak to strong sustainability, in which design is expected to contribute to socio-technical transitions and regenerative development (Salonen et al., 2025). Yet this potential remains underutilised. In response, the introduced Beyond Circular Design framework was developed to enhance the impact of design in addressing critical sustainability issues. The findings of this study suggest that design education should go beyond foundational skills and explicitly integrate systems thinking into design processes.

According to Salonen et al. (2025), companies are no longer solely economic actors but are increasingly seen as contributors to thriving socio-ecological systems. This redefinition challenges designers to play a more systemic and transformative role rather than limiting their contributions to incremental improvements. This shift requires a rethinking of sustainability foundations. As Rockström et al. (2009) emphasise, sustainability requires radical change because the environmental limits known as planetary boundaries are already being exceeded. Therefore, ecological well-being must become the starting point for design, not merely an additional consideration.

To contribute meaningfully to ecological sustainability and operate within planetary boundaries, competence development must move beyond refining the current linear model. It must instead be grounded in long-term, systemic thinking and aimed at achieving transformative impact. Achieving this vision will require collaboration across all sectors of society, along with the vision, courage, and capability to propose and realise alternative models for shaping the future.

Building on this vision, this paper proposes that, to advance strong sustainability, design education and ongoing professional development should focus on deep expertise in sustainability and on how designers can integrate this knowledge into their everyday practice. The framework developed and described in this study illustrates how designers can apply systemic thinking and circular principles in practice, bridging the gap between identified barriers and strong sustainability outcomes.

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Sustainable Design as a Catalyst for Biodiversity Conservation and Circular Economy Innovation: with Reference to the Hospitality Sector in Asia Pacific

Mark Watson

Director

Banyan Group Hotels and Resorts Pte Ltd

Thailand

Introduction

Sustainable design has shifted from being a peripheral concern to becoming a strategic imperative in industries that depend on natural and cultural capital. The hospitality sector, particularly in Asia-Pacific, finds itself at the nexus of this transformation: it both benefits from and impacts biodiversity-rich landscapes and resource-intensive systems. At the same time, the region is grappling with waste generation, resource scarcity, and policy frameworks that are evolving rapidly but unevenly. Against this backdrop, regenerative design offers a lens not only to mitigate harm, but to restore ecosystems and embed circular economy principles into business models.

This paper argues that sustainable design is more than an operational tactic—it is a catalyst for systemic change. By embedding biodiversity conservation and circularity into core business practices, the hospitality industry can redefine growth in ways that are nature positive, economically resilient and socially inclusive. Drawing on examples from Asia-Pacific, the analysis critically examines both achievements and challenges, highlights assessment methods for biodiversity gain and proposes pathways to scale through innovative business models.

Assessing Biodiversity Gain

Central to claims of regenerative impact is the question of how biodiversity gain is assessed. Quantitative methods such as Biodiversity Net Gain frameworks, ecosystem service valuation, and habitat hectare accounting provide measurable outcomes. For example, reforestation projects using the Miyawaki method in Southeast Asia (which focuses on the use of native species) are evaluated through metrics such as species richness, canopy cover and soil carbon sequestration. These provide important data points but can be costly and technically demanding.

Global standards are also shaping practice. The Science-Based Targets for Nature (SBTN) and IUCN's Global Standard for Nature-based Solutions introduce structured methodologies, allowing comparisons across projects. However, their complexity often makes adoption challenging for smaller operators within the hospitality industry. Moreover, qualitative and community-based approaches remain vital. Local communities, particularly those engaged in marine conservation, often act as custodians of ecological knowledge, tracking fish stocks or coral health through participatory monitoring schemes. These indicators may not align neatly with scientific baselines but reflect lived realities and community legitimacy.

Each approach has its limitations: offsetting debates remain unresolved, baselines vary across geographies and funding for long-term monitoring is often absent. The assessment of biodiversity gain in hospitality must therefore integrate scientific rigour with local stewardship if it is to be credible and durable.

From Sustainability to Regeneration

Traditional approaches to sustainable design have centred on minimisation—reducing energy, waste, and emissions. Regenerative design, by contrast, seeks to generate net-positive outcomes. It is grounded in design for the environment and systems thinking, both of which emphasise whole-life cycle analysis and integration with natural and social systems. In Asia-Pacific, where biodiversity hotspots coexist with rapid urbanisation and infrastructure expansion, regenerative design offers a bridge between conservation imperatives and economic growth.

Policy makers are increasingly receptive to these ideas. Singapore's 'City in Nature' strategy demonstrates how biodiversity conservation can be central to national development, whilst Indonesia has positioned sustainable tourism as part of its future growth model. Yet these frameworks remain fragmented and often isolated in pilot projects. The challenge lies not only in proving their ecological and social benefits, but in mainstreaming regenerative design into the business models of hospitality operators across diverse markets in a rapidly emerging, complex competitive environment.

Hospitality Case Studies

One example is the use of the Miyawaki method of afforestation by resorts in Thailand. By planting dense clusters of native species, hotels have created micro or "pocket" forests that support pollinators, sequester carbon, and improve soil health. These initiatives, such as those implemented by Banyan Group (in Laguna Phuket, Thailand) and demonstrate measurable ecological benefits within five years. However, their replication is constrained by land scarcity and the need for sustained maintenance funding, often beyond the lifecycle of a resort project.

Marine conservation efforts in the Maldives provide another lens. Several resorts (e.g. Jumeirah, Anantara, Baros, Banyan Tree, Nova) have established coral nurseries that accelerate reef recovery and provide educational opportunities for guests. Results have been encouraging, with signs of reef regeneration as a result. Yet reliance on guest donations and philanthropic support makes these projects financially fragile. Without access to innovative financing mechanisms such as blue bonds or reef credits, scaling and wider replicability remains a challenge.

In built environments, biophilic architecture, eco-adaptive lighting and shoreline restoration techniques have been incorporated into resort design in Singapore and the Maldives. These interventions minimise ecological disruption while enhancing the guest experience. Nonetheless, the tension between luxury expectations such as expansive, pristine beachfronts and ecological protection continues to challenge operators.

Circularity in hospitality operations has also shown promise. Greywater recycling, on-site composting and food waste segregation are increasingly common across luxury resorts. In South East Asia, AI-powered profiling in kitchens has reduced food waste by close to a third in some situations (e.g. Melia Koh Samui) and their uptake is becoming more prevalent in the region. These initiatives demonstrate operational feasibility and the opportunities presented by new technology, but the absence of consistent infrastructure and fragmented supply chains makes scaling circularity across the region difficult.

Challenges and Pitfalls

Despite these advances, regenerative design within hospitality faces significant systemic hurdles. The absence of established marketplaces for biodiversity credits or ecosystem services prevents operators from monetising ecological gains. Certification schemes, whilst useful, have multiplied to the point of creating fatigue among both operators and consumers. They risk being perceived as marketing tools rather than vehicles for transformation – all of which comes at a time of increasing stakeholder scrutiny in general and concerns from regulators around so-called 'greenwashing' claims in particular.

Financing also presents a barrier. Regenerative projects often demand high upfront capital. Large hotel groups may leverage corporate funds or partnerships, but independent operators struggle to access concessional finance. Banks remain cautious without proven returns, leaving many initiatives underfunded. Policy inconsistency across Asia-Pacific further compounds the problem. Whilst some governments have developed clear sustainability frameworks, others lag, creating uncertainty for investors and operators alike. Finally, guest behaviour remains a limiting factor. Surveys indicate enthusiasm for eco-conscious travel, but widespread evidence on willingness to pay more or compromise on convenience is limited. This misalignment constrains the economic viability of regenerative initiatives.

Business Models for Scalability

The transition from pilot projects to systemic adoption at scale requires innovative business models. Impact-linked guest engagement, where bookings are tied directly to restoration outcomes, creates transparency and personal connection. For example, each stay might finance coral transplantation or forest restoration, embedding biodiversity gain into the guest journey. While these models can inspire, they must evolve into scalable systems supported by robust verification to ensure credibility and prove additionality.

Blended finance provides another avenue. Partnerships in which governments offer guarantees, NGOs provide expertise and hotel groups contribute capital can reduce risk and encourage investment in large-scale regenerative initiatives. Within supply chains, collaborative efforts among hotels to co-invest in infrastructure for waste processing or recycled material procurement can address fragmentation and achieve economies of scale. As highlighted in this paper, technology also offers opportunities. Blockchain-based biodiversity credits, AI waste management tools and satellite monitoring can all enhance accountability and create new value streams.

These models suggest that hospitality can play a pioneering role in demonstrating how biodiversity conservation and circular economy innovation can be embedded within profitable business structures.

Policy and Market Enablers

Government policy is crucial in creating the conditions for scaling regenerative design. Clear regulatory signals, such as biodiversity net gain requirements, provide certainty and encourage investment. Financial incentives in the form of tax breaks for circular construction materials or subsidies for biodiversity-positive projects can ease capital barriers. Regional platforms, such as ASEAN's sustainable tourism initiatives, offer the potential to harmonise standards and promote wider adoption.

Equally important is cultural integration. Policy frameworks must be accompanied by education and awareness campaigns that normalise sustainability as part of hospitality. When guests see regenerative practices as a baseline expectation rather than an optional premium, demand will drive further adoption and give operators the confidence to go further.

Conclusion

Sustainable design has evolved from a discourse of efficiency to a practice that seeks to regenerate ecosystems and communities. In hospitality, it provides a pathway for the industry to move from being a resource user, to becoming an ecosystem steward. However, the path is neither straightforward nor assured. Rigorous biodiversity assessments, critical awareness of systemic barriers, innovative financing models and enabling policy frameworks are all essential preconditions for success.

The hospitality sector has both visibility and influence, making it uniquely positioned to lead. If regenerative design becomes embedded as the standard practice, the sector can demonstrate how biodiversity conservation and circular economy innovation can coexist with luxury and profitability. The direction of travel is clear: those involved in the sector need to integrate rigorous ecological science with cultural legitimacy, align business models with regenerative outcomes, and create policy environments that reward transformation. By doing so, hospitality can become not just a beneficiary of natural capital but a custodian of its renewal.

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The Centre for Sustainable Design ®

For more information, please contact:

Professor Martin Charter

Director

The Centre for Sustainable Design®

Research & Innovation

University for the Creative Arts

Falkner Road

Farnham

Surrey GU9 7DS

UK

t: 00 44 1252 892772

CfSD website: cfsd.org.uk

UCA website: uca.ac.uk

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