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Circular Design for Benchmark: Developing a heuristic tool for circular design

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The shift toward a circular economy requires companies to rethink their product development processes to enhance sustainability, reduce waste, and improve resource efficiency. This thesis investigates how Benchmark can integrate circularity into its design processes by evaluating existing assessment tools, developing a new heuristic tool, and redesigning a product as a case study. The research resulted in two key outcomes: the development of the Circular Potential to Action Tool, a structured design tool for circularity assessment and actionable improvement, and the redesign of an existing product using circular economy principles. The newly developed tool enables companies to assess circularity at different lifecycle stages and translate findings into actionable design improvements. This thesis provides Benchmark with a structured methodology for embedding circularity in product development, aligning with regulatory frameworks and market demands for sustainable solutions.

Circular design, product development, sustainability, lifecycle assessment, design tool

1. Introduction

The linear economy, characterized by a ‘take-make-dispose’ model, has led to resource depletion, environmental degradation, and increasing regulatory pressures. Transitioning to a circular economy (CE) requires companies to integrate sustainable design principles that extend product lifecycles, minimize waste, and optimize material efficiency. This research investigates how Benchmark can implement circularity in product development by analyzing the role of circular economy legislation, integrating circular design strategies through a case study, and developing a structured assessment tool to support decision-making. By addressing these aspects, this study provides a practical approach to facilitating circularity into Benchmark’s design process, ensuring alignment with evolving sustainability standards.

2. Methodology

This research combined literature review, case study analysis, and tool development to integrate circularity into product design. A literature and policy review identified key new circular legislation, circular economy frameworks and lifecycle models, highlighting gaps in existing assessment methods.

A case study tested circular strategies through the redesign of an existing product, using ideation, prototyping, and iterative refinement to ensure feasibility. Insights from this process informed the development of the Circular Potential to Action Tool (CPAT), a structured tool for evaluating and implementing circular strategies. This approach ensured both theoretical depth and practical applicability in circular product development.

3. Circular design research

A key aspect of this research was understanding CE principles and their implications for product development. The study examined aspects like circular perspectives, lifecycle stages, circular loops, and product design strategies aligned with circular business models. Additionally, an analysis of upcoming legislation highlighted the growing regulatory focus on circularity, emphasizing the necessity for companies to adopt sustainable design methodologies or improve their methodologies to comply with upcoming regulations.

3.1 Circularity perspectives

Circularity can be analyzed through different frameworks, each offering a unique lens for understanding how materials and products interact within a circular economy.

The eco-lens perspective provides a system-wide view of circularity, examining the interconnections between product design, business models, and infrastructure. It emphasizes that circularity is not solely product-focused but must be supported by systemic changes, including material flows, take-back systems, and regulatory interventions [1].

The butterfly diagram, developed by the Ellen MacArthur Foundation, illustrates how materials circulate in biological and technical cycles. Biological cycles involve returning materials safely to nature through processes like composting and biodegradation, while technical cycles emphasize reuse, refurbishment, remanufacturing, and recycling to extend material lifespans [2].

Lifecycle stages also plays a critical role in circular design, assessing a product’s entire lifespan from raw material extraction to disposal. This perspective ensures that circular strategies are implemented at all stages, from material sourcing and manufacturing to distribution, use, and end-of-life management, rather than focusing solely on disposal or recycling [3].

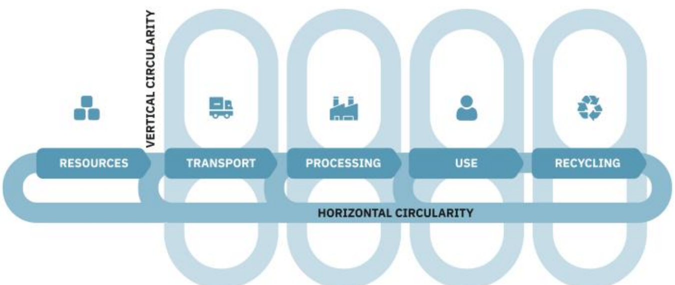

Figure 1. Visualization of vertical and horizontal circularity across the lifecycle stages (adapted from [4])

The research also distinguishes between horizontal and vertical circularity, which is visualized in Figure 1. Horizontal circularity focuses on extending product a products lifetime through reintegration into another lifecycle stage and implementing strategies like reuse, repair, and remanufacturing, while vertical circularity aims to close material loops within specific lifecycle stages, such as reducing waste in production by reintegrating by-products into the manufacturing process [4].

3.2 Product design and business model strategies

Achieving circularity requires an integrated approach, aligning product design strategies with business models to maintain material value for as long as possible. This research explores key circular design strategies, such as design for disassembly, modularity, standardization, and weight reduction, ensuring that products are easier to repair, upgrade, and recycle while minimizing environmental impact [5], [6], [7].

Circular strategies are guided by two fundamental loops: slow loops and close loops. slow loops focus on extending product lifespans through durability, maintenance, repair, and upgradability, reducing the frequency of product replacements. close loops, on the other hand, emphasize material recovery and reuse, ensuring that products and components re-enter the supply chain instead of becoming waste [8].

Beyond product design, business model innovations play a crucial role in supporting circularity. Strategies such as product service systems, leasing systems, and take-back schemes enable companies to retain ownership of materials, facilitating reuse, refurbishment, and recycling. This research highlights the importance of aligning design decisions with business models, ensuring that circular strategies are both economically viable and scalable. Different product design and business model strategies are mapped against slow and close loops in Figure 2 [6], [7].

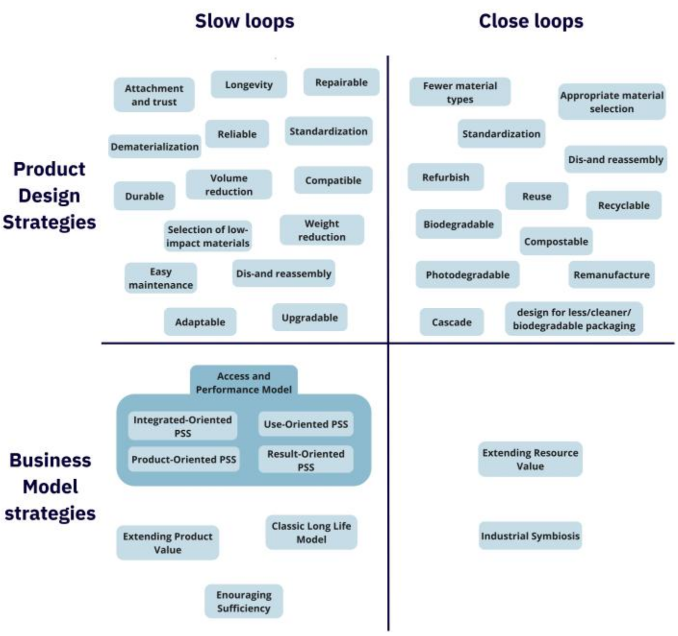

Figure 2. Visualization of product design and business model strategies categorized as slow loops and close loops (based on [7] and own analysis)

3.3 Coming legislation

Regulatory frameworks are increasingly driving the transition toward circular product development. This research examines upcoming legislation, particularly the Ecodesign for Sustainable Products Regulation (ESPR), which introduces sustainability and circularity requirements for products in the European market. The ESPR enforces product-specific rules focused on material efficiency, reparability, recyclability, and digital product passports, ensuring greater transparency and accountability in supply chains [9].

These regulations were considered throughout the research, influencing both the product redesign and the development of the Circular Potential to Action Tool (CPAT) for Benchmark. The findings emphasize that Benchmark must proactively align product development with these regulations, ensuring compliance while leveraging circular strategies as a competitive advantage.

4. Assessing circularity

To effectively integrate circularity into product development, existing circular assessment tools were reviewed and evaluated based on their applicability across different system levels. These tools were analyzed at four levels, namely nano, micro, meso, and macro, each representing a different scale of circularity implementation. The tools and their categorization are visualized in Figure 3.

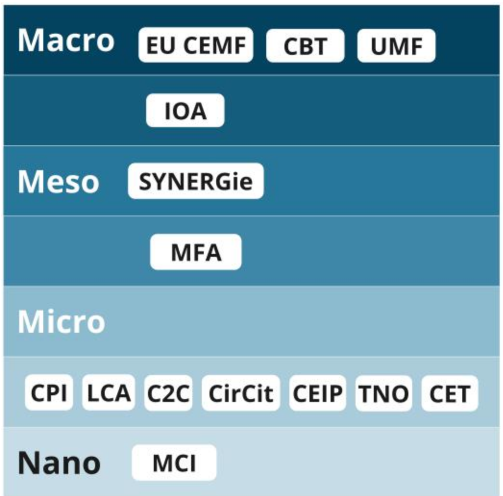

Figure 3. Visualization of assessment tools at different system levels (adapted from [4])

At the nano level, circularity focuses on individual product components and materials. The micro level expands this scope to the product and company level, ensuring that business model strategies align with circular design strategies. The meso level examines industrial symbiosis, where multiple companies collaborate to close material loops by sharing resources and repurposing waste streams. Finally, the macro level considers circularity on a broader societal scale, encompassing national regulations, infrastructure development, and economic systems that support circular transitions [10].

Several circular assessment tools at the nano and micro levels were tested to determine their effectiveness in early-stage product design. The findings indicated that while these tools provide valuable insights, they often lack a structured approach for translating assessment results into concrete design interventions.

Beyond assessment tools, various design approaches for circularity were explored, including hotspot and journey mapping to identify critical areas for improvement and modifying a CE framework [11] to enable system-level interventions. These analyses underscored the need for a new tool that bridges the gap between assessment and design implementation, ensuring that circular strategies are effectively integrated into product development at all lifecycle stages.

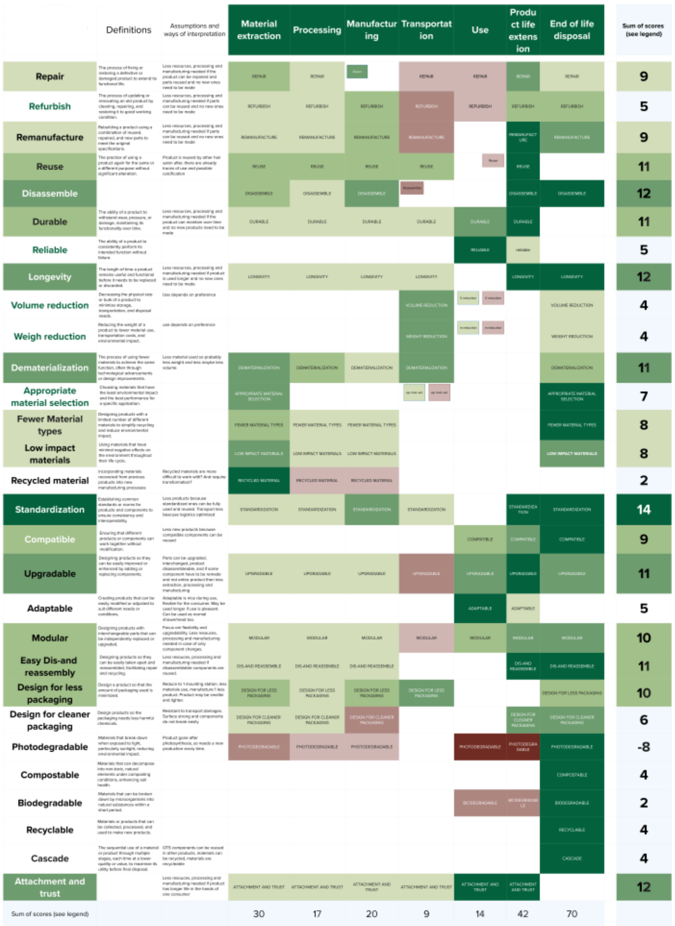

Figure 4. Visualization of the improved framework using all circular design strategies

As a response to these findings, a new framework for circularity assessment and design was developed, incorporating circular design strategies and analyzing their implications across the product lifecycle. The framework is visualized in Figure 4 and represents positive and negative lifecycle impacts using color coding, where green indicates positive contributions to circularity and red highlights challenges or trade-offs. The intensity of these colors reflects the magnitude of impact, providing a clear methodology for evaluating and implementing circular strategies. This framework served as the foundation for the Circular Potential to Action Tool (CPAT), offering a structured approach to assessing circularity throughout the product development process.

5. Case study: Implementing circularity in product redesign

A case study was conducted to apply the developed framework and evaluate its effectiveness in guiding circular product design. The product used in the case study belongs to one of Benchmark's clients. Circularity was integrated into the product redesign by identifying the most impactful strategies based on the framework's assessment. The highest-scoring strategies identified for this specific product were design for standardization, longevity, material reduction, disassembly, upgradability, and attachment & trust. The redesign process followed an iterative approach, incorporating brainstorming, ideation, conceptual development, prototyping, and final product design refinement.

The final redesigned product incorporated modularity, upgradability, durability, standardization, and material efficiency, significantly improving its circular potential. Its ease of disassembly facilitated other circular strategies, such as repairability, remanufacturing, and refurbishment, enabling a longer product lifespan and reducing material waste.

This case study demonstrated how structured circular design methodologies can be effectively applied in real-world product development, reinforcing the practicality of integrating circular strategies into Benchmark's product design process.

6. Developing a circular design tool for Benchmark

In addition to the product redesign, this research focused on developing the Circular Potential to Action Tool (CPAT) to support Benchmark in evaluating and implementing circular strategies systematically. The tool was created by synthesizing circular economy insights, existing assessment methods, and case study findings. Unlike conventional assessment tools, the CPAT functions not only as an evaluation method but also as a design and implementation tool, providing structured guidance for integrating circularity at different lifecycle stages and system levels. The tool was operationalized using Excel software to facilitate use by Benchmark.

	material extraction	Processing	Manufacturing	Transport	Use	Life extension	End of life	
Repair	-1,25	-0,42	-1,25	-6,67	0,00	1,00		-8,58
Remanufacture	-2,50	-0,83	-2,50	-6,67	0,00		1,00	-11,50
Reuse				1,33	0,00		-0,42	0,92
Standardization	1,00	0,33	1,00		0,00		3,00	5,33
Photodegradable					-5,00		5,00	0,00
Weight reduction	1,00	0,33	1,00	2,75	3,00		4,00	12,08
Adaptable	-1,25	-0,42	-1,25		5,00			2,08
	-3,00	-1,00	-3,00	-9,25	3,00	1,00	12,58	

Figure 5. Output of questionnaire presented with circular design strategies mapped against lifecycle stages

CPAT works by assessing a product's current state through a structured set of targeted questions, generating a visual output that highlights circular improvement opportunities across different lifecycle stages (Figure 5). The tool provides design recommendations for each circular strategy and its lifecycle stage, serving as potential circularity requirements. Additionally, the CPAT outputs the results in different ways, such as highlighting and isolation results regarding energy consumption, user experience, and market readiness, ensuring that circularity is addressed from multiple perspectives.

Another feature of CPAT is its ability to map circular strategies at different system levels, helping designers consider the business model, organizational, and infrastructure implications of their decisions. It also includes a trustability score, allowing companies to assess the reliability of their circular design inputs and the tool's outputs (Figure 6).

Trustability score	# unknown questions	# applicable questions
94%	5	90

90% - 100%	Excellent
75% - 90%	Very good
60% - 75%	Good
45% - 60%	Fair

Unknown Questions	Answer
Is the disassembly process intuitive?	Unknown
or accessories from other manufacturers?	Unknown
Is there an existing second-hand market for the product?	Unknown
Can the product's packaging be recycled?	Unknown
Is the product made of bio-based or recycled materials?	Unknown
	5

Figure 6. Overview of trustability score and unknown questions

By integrating CPAT into its product development process, Benchmark gains a practical tool for embedding circularity into future designs. This enables designers to move beyond theoretical circular economy principles take concrete steps toward sustainable, circular product innovation.

7. Conclusion

This research highlights the importance of integrating both product-level circular design strategies and structured assessment tools to create a more sustainable and circular product development approach. The study resulted in a redesigned product that incorporates circular principles, demonstrating how targeted design strategies can enhance sustainability. Additionally, it led to the development of the Circular Potential to Action Tool (CPAT), which provides a holistic framework for evaluating and implementing circularity across different lifecycle stages.

By applying the methodologies developed in this thesis, Benchmark can enhance its product development process, ensuring alignment with circular economy principles and regulatory requirements. The CPAT tool offers a practical and holistic approach for assessing circularity, guiding design teams in making strategic decisions to transition toward a more circular product portfolio.

Future research should focus on extending the list of circular strategies, refining the CPAT to improve its usability, integrating quantitative lifecycle data, and testing its application across a broader range of products.

References

[1] J. Konietzko, N. Bocken, and E. J. Hultink, “A tool to analyze, ideate and develop circular innovation ecosystems,” *Sustainability (Switzerland)*, vol. 12, no. 1, 2020, doi: 10.3390/SU12010417.

[2] “The Butterfly Diagram: Visualising the Circular Economy.” Accessed: Jan. 17, 2025. [Online]. Available: https://www.ellenmacarthurfoundation.org/circular-economy-diagram

[3] “Climate Change and the Life Cycle of Stuff | Climate Change | US EPA.” Accessed: Jan. 17, 2025. [Online]. Available: https://19january2017snapshot.epa.gov/climatechange/climate-change-and-life-cycle-stuff_.html

[4] “Circular Economy - Beginner’s Guide - Ecochain - LCA software company.” Accessed: Aug. 27, 2024. [Online]. Available: https://ecochain.com/blog/circular-economy-guide/

[5] M. Moreno, C. De los Rios, Z. Rowe, and F. Charnley, “A conceptual framework for circular design,” *Sustainability (Switzerland)*, vol. 8, no. 9, Sep. 2016, doi: 10.3390/su8090937.

[6] N. M. P. Bocken, I. de Pauw, C. Bakker, and B. van der Grinten, “Product design and business model strategies for a circular economy,” *Journal of Industrial and Production Engineering*, vol. 33, no. 5, pp. 308–320, Jul. 2016, doi: 10.1080/21681015.2016.1172124.

[7] M. Yang and S. Evans, “Product-service system business model archetypes and sustainability,” *J Clean Prod*, vol. 220, pp. 1156–1166, May 2019, doi: 10.1016/j.jclepro.2019.02.067.

[8] A. Mestre and T. Cooper, “Circular product design. A multiple loops life cycle design approach for the circular economy,” *Design Journal*, vol. 20, pp. S1620–S1635, 2017, doi: 10.1080/14606925.2017.1352686.

[9] P. Office of the European Union L- and L. Luxembourg, “Establishing a framework for the setting of ecodesign requirements for sustainable products.” [Online]. Available: http://data.europa.eu/eli/reg/2024/1781/oj

[10] M. Saidani, B. Yannou, Y. Leroy, and F. Cluzel, “How to assess product performance in the circular economy? Proposed requirements for the design of a circularity measurement framework,” *Recycling*, vol. 2, no. 1, 2017, doi: 10.3390/recycling2010006.

[11] C. Garcia-Saravia Ortiz-de-Montellano, A. Ghannadzadeh, and Y. van der Meer, “The CIRCULAR pathway: a new educational methodology for exploratory circular value chain redesign,” *Frontiers in Sustainability*, vol. 4, 2023, doi: 10.3389/frsus.2023.1197659.