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Toward Sustainable Innovation: A Participatory Study on Designers' Tool Needs for Circular Product Design

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ABSTRACT:
The circular economy (CE) provides a framework for sustainable production and consumption, with circular design playing a critical role in shifting from linear systems to models that promote continuous reuse of materials and products. However, many existing design tools focus on high-level strategies that assume entirely new business models, making them less applicable to production-oriented industries. This study explores the practical needs of designers in developing tools that support early-stage circular product ideation, where the majority of a product's sustainability impacts are determined. We conducted two co-design workshops using a participatory design approach to surface user needs and assess current tools. Participants were graduate students in industrial design with foundational CE knowledge and experience in circular design projects. In the first workshop, participants tackled rapid design challenges and evaluated the usability and limitations of existing tools. In the second, researchers introduced key CE frameworks — such as the butterfly diagram, 9R framework, and Design for X (DfX) strategies — which participants used to prototype a circular product design card tool.
The study reveals specific, practice-based needs that can guide the development of user-centred circular design tools. These insights offer a foundation for creating more actionable, production-aligned resources to support CE transitions.

Keywords: Circular Economy, Circular Product Design, New Product Development, Product Circularity, Design for X(DfX), Design Strategy

1. Introduction

As global resource consumption intensifies, the circular economy (CE) is regarded as a key pathway toward sustainable production, consumption, and lifestyles (Ellen MacArthur Foundation, 2013; Nikolaou et al., 2021). Circular design is vital in this transition by supporting the shift from linear systems to CE (Ellen MacArthur Foundation, 2024). However, realising effective circularity requires not only design interventions during production but also business models that enable products and materials to circulate over time.

For industries grounded in linear production, transitioning to circular business models is challenging but also offers opportunities for designers to propose practical strategies based on existing resources. Although several design tools — such as the Use2Use Design Toolkit (Rexfelt & Selvefors, 2021), the Circularity Deck (Konietzko et al., 2020) and the Sustainable Design Cards (Ræbild & Hasling, 2019) — provide guidance on high-level strategies and new business models, practical tools for designers in production-oriented industries remain scarce. Previous studies have indicated that product

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design and development can determine up to 80% of a product's overall sustainability performance (Albæk et al., 2020; Diaz et al., 2022; IRP, 2018). Therefore, developing tools that can support designers in making informed decisions during concept development of the early design stages is crucial for effectively embedding CE principles into product design and ultimately creating more sustainable products.

This study is the first stage of our project, which aims to develop design strategy tools to support the early stages of circular product design (CPD). Using a participatory design (PD) approach, we emphasise collaboration, empowerment, and shared learning to deepen understanding of user needs. In this stage, four designers participated in co-creation workshops to explore their need for support for design tools in CPD practice. The following sections describe the research motivation and methods, present findings from the two workshops and follow-up interviews held in late 2024, and outline directions for future research.

2. Background and Motivation

2.1 Circular Product Design (CPD)

The circular economy (CE) has been recognised as a key strategy for addressing environmental and resource challenges, helping businesses improve competitiveness and drive sustainable growth (Ellen MacArthur Foundation, 2013). However, implementing CE requires internal changes and external collaboration with supply chains and consumers (Moreno et al., 2016).

For companies oriented toward linear production, this transition often faces practical resistance. Starting with existing resources and adopting gradual strategies can help ease this process (Sumter et al., 2017). As a core of CE, circular product design (CPD) is especially important in the early product development, directly influencing sustainability outcomes (Albæk et al., 2020; Diaz et al., 2022; IRP, 2018).

By applying circular strategies through design, businesses can gradually adapt to CE and reduce resistance to change. Designers play a key role in this process, helping develop sustainable product ideas to support transformation. However, designers often lack practical strategies and tools to turn CE principles into actionable plans. Existing research also shows that the early stages of new product development —specifically planning and concept development — are critical to CPD outcomes and the phase where designers have more access to resources and strategic guidance (Aguiar et al., 2022). Therefore, developing systematic and targeted tools to support designers at this early stage has become critical (Ellen MacArthur Foundation, 2021a).

2.2 Design Support Tool

Design strategies are often implemented through tools such as worksheets, virtual whiteboards, cards, and websites (Abdelmeguid et al., 2024). Card-based tools stand out for their concise, visual format, helping integrate knowledge, support creativity, and deepen understanding (Roy & Warren, 2019). Cards also help designers communicate with non-designers, build consensus, and increase engagement in the early design stages (Aarts et al., 2020; Roy & Warren, 2019). For this reason, this study focuses on card-based tools to explore designers' needs.

For many companies adept in linear production, transitioning to a circular business model presents a significant challenge. However, many existing circular design tools frequently emphasise high-level strategies that necessitate the creation of a whole new circular business model, like the Use2Use Design Toolkit (Rexfelt & Selvefors, 2021). There is an apparent demand for tools tailored to production-oriented industries. To support the early-stage CPD, tools must be developed based on practical design challenges, helping designers bridge strategy with daily practice and advancing CE adoption.

2.3 Participatory Design (PD)

Participatory design (PD) empowers users to shape design outcomes through active collaboration and mutual learning (Simonsen & Robertson, 2013). PD promotes equal participation, reduces power imbalances, and ensures that diverse needs and values are reflected in the final results. For designers, PD offers opportunities to deeply understand the real needs while engaging users in developing realistic solutions. It also helps shift technology decisions away from purely market-driven logic, supporting fairness and inclusion.

In this study, PD ensures that designers' perspectives guide tool development. By simulating practical design idea-generating processes and co-creating prototypes for a card tool, we aim to uncover deeper needs and strengthen the relevance and effectiveness of CPD support tools.

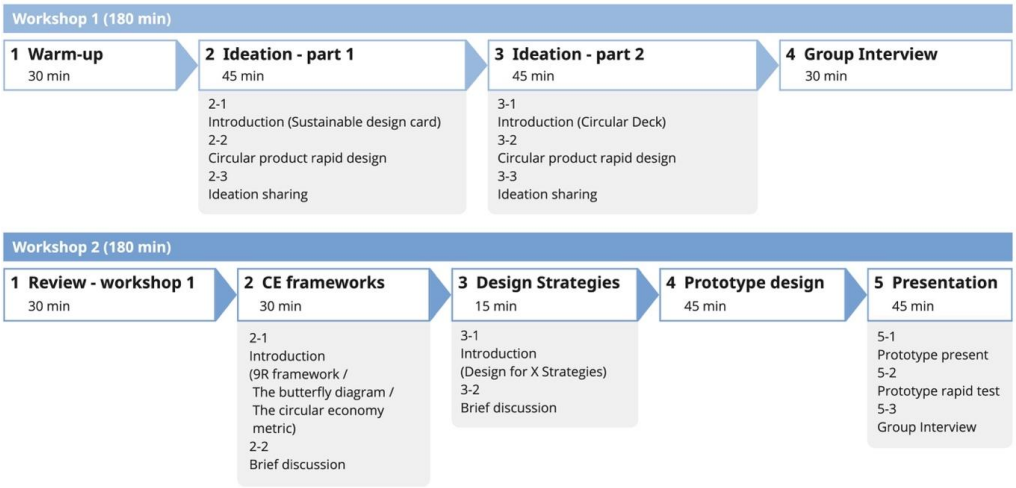

Figure 1: PD workshops process

3. Methods

3.1 Participants

To better understand designers' practical needs for design supporting tools in circular product design (CPD), two selection criteria were used: (1) participants had knowledge of the circular economy (CE) but were not specialists in circular design, and (2) participants had prior experience using card-based tools for circular design projects. Four designers meeting these criteria were invited. All were graduate students in industrial

design who had completed a semester course on sustainable design, covering core CE concepts. Each participant had experience using the Use2Use Design Toolkit (Rexfelt & Selvefors, 2021) at least twice for circular design project ideation, proposal development and presentation.

3.2 Study Procedure

Two participatory design (PD) workshops were conducted to explore designers' needs for CPD tools from their perspectives. To further capture their insights, follow-up interviews were held after the workshops. Both workshops included four designers (3 female and 1 male) and two researchers. Each session lasted three hours and was completed in two separate days. The procedure is shown in Figure 1.

Figure 2: Participants discussed existing toolkits in Workshop 1(Left) and prototyped their CPD card tool in Workshop 3 (Right).

The first workshop focused on understanding how card-based tools support circular design and identifying designers' needs and preferences. Participants first reviewed CE concepts and shared their past experiences with circular design tools, particularly the Use2Use Design Toolkit (see Figure 2). Then, they used two circular/sustainable design card decks — the Circularity Deck (Konietzko et al., 2020) and the Sustainable Design Cards (Ræbild & Hasling, 2019)in two rapid design sections (see Figure 2) — to generate circular product design concepts. Group discussions followed, gathering feedback on tool usability, effectiveness, and suggestions for improvement. These insights informed the second workshop and helped assess the potential of cards as design tools.

Based on the first session, the second workshop explored how card content and formats could better support practical use. Additional CE resources were provided, including the butterfly diagram (Ellen MacArthur Foundation, 2021b), the PBL circularity ladder, also known as the 9R framework (Potting et al., 2018), and Design for X (DfX) strategies related to CPD (Aguiar et al., 2022). Participants were then asked to prototype new card-based tool designs; they could use the previous three decks along with two new ones: The Cambridge Sustainable Design Strategy Cards (Dusch et al., 2017) and The Sharing Economy Design Cards (Fedosov et al., 2019) as reference (Figure 3).

After developing their prototypes (Figure 3), participants presented their results and tested their prototypes by applying them to the same task used in the first workshop. Following the trial, they provided feedback on their adjustments, with reasons grounded in their experience. This process generated valuable input on information structure, layout, and usability, further clarifying how design strategies could be better categorised and applied.

Figure 4. Prototype designs created by participants: P1 designed strategy cards with an accompanying index; P2 created two styles of strategy cards along with 9R introduction cards and a review chart; P3 combined strategy cards with a short-, mid-, and long-term planning sheet and evaluation form; P4 developed problem-driven strategy cards.

Semi-structured follow-up interviews were conducted after the workshops to further explore designers' experiences and perspectives. Three interviews were held face-to-face; one was conducted online. The interviews focused on use contexts, content preferences, and language considerations for card-based tools. The main questions included:

Q1. Do you think circular design card-based tools should be regularly updated? Why or why not?

Q2. In what situations would you prefer to use a structured framework, and when would you lean toward free ideation?

Q3. In your experience, how do you think card-based tools can support the design process?

(1) Generating circular product design ideas
(2) Organising ideas or clarifying design directions
(3) Facilitating team communication and collaboration

Q4. Why do you think participants generally did not expect the card tools to include specific design implementation methods?

Q5. Regarding convergence tools in the design process:

(1) At which stage(s) of product design or innovation do you think convergence should occur?
(2) Why do you think convergence is necessary?

Q6. Should card-based tools be presented in the user's native language or remain in English? Why?

This interview aimed to deeply understand designers' practical needs and challenges in CPD, offering essential input for future tool development and strategy refinement.

4. Findings

All workshops and interviews were audio-recorded and transcribed for analysis. Transcripts were coded using ATLAS.ti. A three-part coding system was used to protect

participant privacy: participant (P1–P4), data source (WS1: Workshop 1; WS2: Workshop 2; FI: Follow-up Interview), and workshop section or question number. For example, P3-WS1-4 refers to Participant 3 speaking in Workshop 1's section 4.

Thematic analysis was conducted following Braun and Clarke (2006) approach, which emphasises flexible, theory-neutral identification and organisation of themes. The data analysis followed these steps: reading transcripts carefully, using Miro's sticky notes to record participants' ideas related to design tools and product design, generating initial codes, then grouping similar or related codes into potential themes, reviewing, refining and merging these themes as needed, and finally defining and naming each theme to clarify scope and content.

The workshops and interviews data analysis identified nine themes across three categories —information, usability, and visualisation — that inform the future development of card-based CPD tools. Key findings and representative quotes are summarised below:

- **Theme 1: Usage Context and Applicability**

Participants emphasised that card-based tool size, content, and language should be adapted to different usage contexts, including whether the user works individually or in a team. They also highlighted the importance of matching content complexity to the user's knowledge level and providing local language versions to improve accessibility and reduce cognitive barriers. Cultural differences in thinking styles were also noted as a factor influencing tool preferences.

"I think this size is suitable for team use; the other one works better for skimming individually first, then sharing." (P3-WS1-4)

"If it's for Taiwanese designers or students, then I think the Chinese version would work better." (P4-FI-Q6)

- **Theme 2: Content Presentation and Structure**

Participants preferred explicit, concise content with minimal overload. They suggested using hashtags or keywords to show relationships between cards and prevent disconnection or redundancy. Structuring content with visual hierarchy and presenting supplementary information via QR codes were also recommended to enhance clarity and reading efficiency.

"Providing definitions, examples, and illustrations should help users know the direction... Don't give too little, and don't overload them either." (P2-WS2-5-2)

- **Theme 3: Content Types and Diversity**

Participants expected card-based tools to include a broader range of design domains, such as UI/UX and service systems, to reflect current industry practices. While case examples and designer-curated illustrations were helpful in communicating strategy, some participants believed clear definitions alone could suffice. Including potential challenges was suggested to provoke deeper thinking during ideation.

"The cards may be outdated... mostly about physical products, but now with UI/UX or service system in CE, they are scarce in the cards." (P2-WS1-1)

- **Theme 4: Future Updates and Expansion**

All participants emphasised the importance of regular updates and flexible expansion to keep pace with the evolving circular economy landscape. They suggested

updating digital versions, releasing renewed versions for physical cards to reflect the evolution of design strategies, and including blank cards for user-customised content. These features were seen as essential for maintaining relevance and encouraging long-term use.

"It keeps evolving… You cannot always rely on the same theories or old case studies." (P4-FI-Q1)

- **Theme 5: Usage preferences**

Participants valued structured guidance to help them start using the tool effectively, but also emphasised the need for flexibility. Many preferred to begin with personal experience before referring to the cards. Some only used the cards when encountering creative blocks, reflecting a preference for optional rather than prescriptive use.

"Prefer tools with a framework, I would have a path to follow… Without it, I may feel lost in the beginning." (P3-WS1-4)

- **Theme 6: Concept Integration and Evaluation**

Participants noted that while cards support idea generation, they should also assist with concept refinement. Some suggested integrating checklists or metrics to evaluate circularity. Others believed convergence could occur without additional tools, depending on the team's/person's design capacity.

"It might be more critical to help them converge in later-stage… Especially for teams that include non-design members who struggle to narrow ideas down." (P3-FI-Q5)

- **Theme 7: Interactivity and Usability**

Participants expected the cards to be easy to operate, clearly guided, and quickly searchable to support efficient use during design ideation. Physical cards and gamified formats were seen as engaging and helpful for team interaction, with the size of the Cambridge Sustainable Design Strategy Cards (similar to A6-sized) considered the most practical. Paper formats were preferred for in-person collaboration due to their intuitive handling. At the same time, digital tools were favoured for remote settings and translation support, though they required more time to learn. Participants suggested combining both formats depending on context to enhance overall usability.

"Looking at the cards together encourages the discussion." (P1-FI-Q3-3)

"Paper is faster—everyone reads and we can discuss right away." (P2-WS1-1)

- **Theme 8: Efficient Search and Filtering**

Participants highlighted the need for efficient filtering mechanisms to locate relevant content quickly. They recommended classifying cards by life cycle stages or the 9R framework and using elements like guiding questions, hashtags, numbering, and colour coding to enhance navigation and usability.

"It can help filter cards quickly for considering their need." (P4-WS2-5-1)

- **Theme 9: Graphics and Visualisation Aids**

Visual elements such as icons, colour tags, and custom illustrations effectively improved comprehension, reduced cognitive load, and enhanced user experience. Participants especially valued illustrations that were thoughtfully interpreted by the tool developers to clarify abstract design strategies.

"Only providing text may feel stressed… even simple images make it more pleasant." (P3-WS1-4)

These nine themes highlight the need for CPD tools to adapt content and format to context, audience, language, and cultural differences. Information should be concise, structured, and cover diverse design fields, supported by examples, visuals, and challenges to foster creativity. Flexibility, regular updates, and optional user customisation are essential for long-term usability. Designers preferred tools that balance structured guidance with creative freedom and suggested incorporating evaluation tools to support circularity assessment. Ease of use, interactivity, and gamification enhanced engagement, with physical and digital formats recommended depending on context. Clear organisation, filtering, and illustration further improved the overall experience. These findings provide a foundation for developing more practical, user-centred CPD tools in the future.

5. Discussion

This study explored designers' practical needs when applying circular product design (CPD) strategy tools. Through participatory workshops and thematic analysis, nine key themes were identified, highlighting expectations around contextual adaptability, clear structure, diverse content, and intuitive interaction. The findings suggest that practical CPD tools should be flexible, easy to use, and aligned with individual and team-based design practice realities.

This research offers not only practical insights into current gaps in circular design support but also an initial framework for developing user-centred, practice-oriented design tools. The card prototypes created in this research offer a valuable foundation for future tool development, particularly in aligning design strategies with circular economy principles.

Building on these findings, future work will focus on developing a structured and clearly categorised card set, incorporating localised language versions, precise definitions, and regionally relevant case studies. These enhancements aim to reduce language barriers, improve contextual relevance, and better support designers in identifying appropriate strategies for circular innovation.

It should be noted that this study involved graduate design students who may not fully represent the experience and challenges faced by industry professionals. Future development and validation of the card tools will include testing with professional product/industrial designers in a design ideation workshop to ensure practical applicability and enhance the tool's effectiveness in practical settings.

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