European Journal of Sustainable Development (2025), **14**, 3, 399-411 ISSN: 2239-5938
Doi: 10.14207/ejsd.2025.v14n3p399

The Implementation of Circular Design Strategies at the Micro and Meso Levels: Evidence from Taiwan's Manufacturing Firms

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ABSTRACT:
This study explores how circular design strategies are interpreted and applied at the micro and meso levels. Using a two-stage explanatory mixed-methods design. Stage 1 combined expert surveys and interviews to construct level-specific strategy frameworks, resulting in five strategies and 19 key items at the micro level, and six strategies and 24 key items at the meso level. In Stage 2, a questionnaire distributed to 60 Taiwan-based practitioners with circular design experience, revealed broadly aligned quantitative scores across levels, while qualitative insights exposed divergent implementation logic. Micro-level actors prioritized usability, modularity, and behavioral incentives, while meso-level respondents emphasized reverse logistics, system integration, and long-term infrastructure. These findings reflect role-based priorities shaped by daily practice and system responsibilities. This study offers a level-sensitive framework that clarifies how CDSs are evaluated and enacted across levels, providing theoretical insight and practical guidance for design, policy, and cross-level collaboration.

Keywords: circular design, circular design strategies, system-level design, circular economy, sustainability

1. Introduction

The linear economic model of "take–make–use–dispose" has continued to strain global resources and ecosystems (Moreno et al., 2016). In response, the circular economy (CE) has gained momentum, promoting regenerative strategies that close, slow, and narrow material loops (Geissdoerfer et al., 2017). Notably, the Ellen MacArthur Foundation and IDEO (2017) proposed six core circular design strategies (CDSs): product life extension, close loops, product as service, embedding intelligence, modularity, and smart material choices—provide practical entry points for designers. Although CE policies have been adopted globally, such as Taiwan's "Zero Waste 2050" agenda—how CDSs are applied across different system levels remains unclear. Vanhamäki et al. (2019) classify CE actors into three levels: micro (product, material, and business model design), meso (industrial clustering and value-chain collaboration), and macro (policy and governance). However, most CE design research and tools underexplore the cognitive and contextual differences across levels, limiting implementation effectiveness.

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This study focuses on micro- and meso-level practitioners engaged in circular design within Taiwan's manufacturing sector. Using a modified Delphi method and mixed-method analysis, it aims to:

(1) examine how circular design strategies are interpreted and evaluated across system levels, highlighting differences in understanding between levels.
(2) identify practical and cognitive gaps that inform level-sensitive design planning, especially those shaped by differing roles and constraints.
(3) synthesize findings into a contextualized framework for level-appropriate implementation, grounded in the realities of multi-level design practice.

2. Theoretical Background

2.1 Circular Economy (CE)

Amid growing concerns over resource depletion and environmental degradation, the CE has emerged as a key strategy for sustainable development. CE shifts away from the linear "produce–use–dispose" model, focusing on resource recirculation, product life extension, and systemic efficiency (Moreno et al., 2016). Governments and businesses worldwide are advancing CE through technological and business model innovation to boost competitiveness while reducing environmental impact. Yet CE is more than a philosophical shift—it requires fundamental changes in design logic and business practices. Studies show that policy and technology alone are insufficient; context-specific design strategies are essential for implementation across system levels (Bocken et al., 2016; Geissdoerfer et al., 2017). Developing level-sensitive circular design framework is therefore a critical step toward effective CE adoption—and serves as the foundation of this study.

2.2 Circular Design

Designers have long played a key role in shaping consumption systems through material choices and product lifecycles. "Green design" and "eco-design" emerged in the 1970s to reduce environmental harm but remained within a linear economy mindset (Roy, 1994). Not until the 1990s did "sustainable design" begin integrating ecological and social concerns (McLennan, 2004). In the 2000s, "Design for Sustainability" (DfS) emphasized aligning design with business models. Ceschin & Gaziulusoy (2016) classified DfS innovations into four levels: product, product–service system, spatial–social, and socio-technical. The European Union has also emphasized design's role in recycling and product longevity. To promote CE, the Ellen MacArthur Foundation and IDEO introduced a circular design guide advocating restorative and systemic approaches. The Circular Design Guide promotes a vision where design is fundamentally circular, enabling both ecological regeneration and business value (EMF & IDEO, 2017).

2.3 Circular Design Strategies (CDSs)

While many companies possess the capability to manage resources, they often lack strategic design guidance for implementing circular transitions (Nußholz, 2017). CDSs are essential for bridging this gap, offering innovation pathways for CE-aligned products and services. However, due to the field's emerging nature, a universally adopted classification of CDSs remains elusive. This study defines CDSs as "strategic action plans designed to support CE through sustainable and competitive design interventions."

Urbinati et al. (2018) grouped CDSs into two categories: reconstructing the value network and redesigning customer interactions. Konietzko et al. (2020) proposed five strategy types—narrow, slow, close, regenerate, and inform—emphasizing the redesign of material and energy flows. EMF and IDEO (2017) outlined six major CDSs: (1) Close loop/take back, (2) Embedding intelligence, (3) Modularity, (4) Product as service, (5) Product life extension, and (6) Smart material choices, as shown in Figure 1. These strategies, originally developed to guide circular design initiatives, have been widely adopted across diverse implementation contexts and now provide a practical foundation for this study's cross-level analysis.

Figure 1: *The six circular design strategies (CDSs)*
(Adapted from EMF & IDEO https://www.circulardesignguide.com/resources).

2.4 Micro-Level vs. Meso-Level

The implementation of circular design strategies (CDSs) varies across system levels. As defined by Moreno et al. (2016) and Bocken et al. (2016), the micro level focuses on optimizing individual products or services, while the meso level involves business networks, industrial clusters, and regional platforms. However, current design tools largely remain product-oriented and offer limited guidance for meso-level applications (De los Rios & Charnley, 2017). To address this, the study compares how CDSs are interpreted across levels, identifying misalignments and informing the development of level-sensitive design frameworks.

2.5 Circular Design Strategies Across System Levels

To support level-sensitive CDS development, this study builds on DfX (Design for X) principles. Holt & Barnes (2010) emphasized aligning DfX strategies with the broader design process, while Moreno et al. (2016) linked DfX to circularity by highlighting the importance of contextual fit. Drawing on these insights, as well as the Circular Design Guide (2017) and De los Rios & Charnley (2017), this study constructs a matrix of six CDSs and corresponding evaluation items to analyze how strategies are interpreted at micro and meso levels, as shown in Table 1. This typology supports the identification of cross-level gaps and practical alignment in subsequent sections.

Table 1: The six CDSs with key items

Strategies	Key Items		Reference
Close loop/ Take-back	I-1	ease of recycling and maintenance	Wallner et al. (2020)
	I-2	renewability and reusability	EMF & IDEO (2017)
	I-3	product upgradability	Bakker et al. (2019)
	I-4	cross-sector applications	EMF & IDEO (2017)
	I-5	ease of disassembly and reassembly	De los Rios & Charnley (2017)
	I-6	internal loop recycling mechanism	Ramakrishna & Ramasubramanian (2024)
Embedding intelligence	II-1	embedded smart technologies	EMF & IDEO (2017)
	II-2	smart-enabled value-added functions	Urbinati et al. (2025)
	II-3	enhanced service experience	Kim (2023)
	II-4	digitalized smart management	Urbinati et al. (2025)
Modularity	III-1	repairable module	Asión-Suñer & López-Forniés (2021)
	III-2	remanufacturable module	EMF & IDEO (2017)
	III-3	upgradeable module	Asión-Suñer & López-Forniés (2021)
	III-4	customizable module	EMF & IDEO (2017)
Product as service	IV-1	multi-functional product-service models (sharing, renting, swapping)	EMF & IDEO (2017)
	IV-2	maximized product utilization	Moreno et al. (2016)
	IV-3	high product durability	Wallner et al. (2020)
	IV-4	enhanced user interaction	De los Rios & Charnley (2017)
	IV-5	resource-efficient design	De los Rios & Charnley (2017)
Product life extension	V-1	extended product lifespan	Bakker et al. (2019); EMF & IDEO (2017)
	V-2	ease of repair and refurbishment	Bakker et al. (2019)
	V-3	ease of disassembly and reassembly	Dumée (2022)
	V-4	product upgradability	Bakker et al. (2019)
	V-5	reliable and durable components	Dumée (2022)
	V-6	timeless aesthetic design	Wallner et al. (2020)
	V-7	design for emotional attachment	Wallner et al. (2020)
	V-8	accessible product-service system	Moreno et al. (2016)
Smart material choices	VI-1	easily recyclable materials	Dumée (2022)
	VI-2	reliable and durable materials	Ramakrishna & Ramasubramanian (2024)
	VI-3	restricted or prohibited hazardous materials	Dumée (2022)
	VI-4	biomimetic or biogenic materials	Vanhamäki et al. (2019)

Source: This study

3. Methods

To address the limited integration of circular design strategies, design methods, and systemic levels, this study adopts a mixed-method approach combining the Modified Delphi Method (MDM) and a two-stage design.

3.1 Research Design and Participants

Stage 1: Research Tool Construction and Expert Evaluation. Based on the literature review, an initial list of CDSs and key items was compiled (see Table 1). Semi-structured interviews and a 5-point Likert scale survey were conducted with 10 experts from industry, academia, and research institutions, representing both micro- and meso-levels. Table 2 represents the profiles of 10 experts at the micro and meso levels. Their feedback refined a set of strategies and items with high relevance and alignment, which formed the basis for the Stage 2 questionnaire.

Table 2: Profiles of circular design experts at the micro and meso levels

Level	Code	Domain	Experience	Expertise
Micro-level	A1	Industry	10+years	sustainable product design
	A2	Industry	10+ years	circular material innovation
	A3	Academia	10+ years	material culture, circularity, and design
	A4	Academia	10+ years	second hand product reuse initiatives
	A5	Research	10+ years	circular information design
Meso-level	B1	Industry	15+ years	environmental advocacy and promotion
	B2	Industry	15+ years	plastic R&D and circular manufacturing
	B3	Industry	20+ years	circular economy research and education
	B4	Academia	20+ years	circular design and higher education
	B5	Research	20+ years	resource circulation design

Source: This study

Stage 2: Survey Implementation and Comparative Analysis. A questionnaire was administered to 60 practitioners with hands-on experience at the micro and meso levels. To ensure sample diversity, purposive, snowball, and convenience sampling were combined (Goodman, 1961; Noy, 2008). The 60 respondents represented a diverse range of professional roles and domains. At the micro level, participants included product designers, entrepreneurs, and sustainability-focused practitioners. At the meso level, respondents consisted of researchers, industry managers, and strategy consultants specializing in circular economy initiatives. Each level comprised 30 participants.

3.2 Research Analysis Method

This study employed an explanatory mixed-method design. Quantitative and qualitative data were integrated to enhance interpretability and analytical depth (Van Griensven et al, 2014). Stage 1 Analysis – Expert evaluation: A 5-point Likert scale assessed the suitability and consistency of each strategy and item. Suitability was determined via mean, mode, and full-score ratio, with high agreement defined as mean≥4 and mode=5.

Consistency was categorized as high (SD≤0.50/ QD≤0.60), medium (0.50<SD≤1.00/0.60<QD≤1.00), or low (SD>1.00), based on standard deviation and quartile deviation. These metrics guided item refinement. Expert feedback was thematically analyzed to refine the clarity and delineation of each strategy.

Stage 2 Analysis – Survey and comparative analysis. Quantitative analysis involved calculating means and standard deviations. Independent sample t-tests ($p<0.05$) assessed level-based differences. Open-ended responses were thematically analyzed to extract practitioner insights, contextual challenges, and identify level-specific interpretations. The process was iteratively reviewed and cross-checked by multiple researchers to ensure analytical consistency and reliability. Two strategies were selected for in-depth discussion: (1) one exhibiting statistically significant differences; and (2) those with the highest and lowest average scores. This ensured analytical rigor while providing contextual depth. By contrasting expert evaluations and practitioner interpretations across system levels, the study highlights the contextual nuances and role-based priorities that influence strategy adoption.

4. Results

4.1 Stage 1: Research Tool Construction and Expert Evaluation

This study developed a circular design framework comprising six strategies and 31 key items, drawing on IDEO & EMF (2017) and the DfX framework by Moreno et al. (2016). This framework structured the expert evaluations conducted at both micro and meso levels, with results presented in Tables 3 and 4. Experts assessed the appropriateness and consistency of each strategy and key item.

At the micro level, strategy scores ranged from 3.65 to 4.85, and item scores from 3.00 to 5.00. While overall ratings were favorable, several items raised concerns regarding conceptual clarity. The "Product life extension" strategy was positively received but exhibited internal redundancy due to overlapping meanings across items, prompting suggestions for semantic refinement. [A1, A2, A4, A5]. Likewise, the "Product as service" and "Close loop/take back" strategies were critiqued for vague boundaries and inconsistent terminology, leading to refinements summarized in Table 4 and further discussed in Sections 5. [A1, A3, A4]. The "Embedded intelligence" strategy received the lowest mean score (M=3.65), falling below the 4.00 threshold. Experts questioned its alignment with core circular design principles and noted its limited cross-sector relevance, recommending context-specific implementation [A1, A3, A5].

At the meso level, appropriateness scores for the six strategies ranged from 4.36 to 4.88, and item scores from 3.60 to 5.00. Compared to the micro level, meso-level responses demonstrated higher consensus and more coherent logic. Except for the "Product as service" strategy, which displayed only moderate consistency, the other five strategies achieved high agreement, suggesting strong potential for systemic application. However, items such as "biomimetic or biogenic materials" and "cross-sector applications" were flagged for imprecise definitions or limited practical relevance, requiring further clarification [B2, B5].

Table 3: Assessment of CDSs and key items from micro and meso-level perspectives

Strategies and Key Items	Micro-level					Meso-level				
	Relevance			Consensus		Relevance			Consensus	
	Mean	Mo	F.S%	QD	SD	Mean	Mo	F.S%	QD	SD
Close loop/ take back	**4.53**	**5**	**0.60**	**0.50**	**0.49**	**4.63**	**5**	**0.73**	**0.33**	**0.45**
ease of recycling and maintenance	4.60	5	0.60	0.64	0.55	4.80	5	0.80	0.00	0.45
renewability and reusability	4.80	5	0.80	0.50	0.45	4.80	5	0.80	0.00	0.45
product upgradability	4.40	4	0.40	0.50	0.55	4.20	5	0.40	0.50	0.84
cross-sector applications	4.00	3	0.40	1.00	1.00	4.20	5	0.60	0.50	1.30@
ease of disassembly and reassembly	4.80	5	0.80	1.00	0.45	5.00	5	1.00	0.00	0.00
internal loop recycling mechanism	4.60	5	0.60	0.50	0.55	4.80	5	0.80	0.00	0.45
Embedding intelligence	**3.65#**	**4**	**0.25**	**0.38**	**0.74**	**4.55**	**5**	**0.70**	**0.50**	**0.51**
embedded smart technologies	3.40#	4	0.20	0.81	1.52@	4.00	5	0.60	1.00	1.41@
smart-enabled value-added functions	3.60#	4	0.00	0.69	0.55	4.60	5	0.60	0.50	0.55
enhanced service experience	3.40#	5	0.40	1.17@	1.67@	4.80	5	0.80	0.00	0.45
digitalized smart management	4.20	5	0.40	1.17@	0.84	4.80	5	0.80	0.00	0.45
Modularity (micro, n=4)	**4.55**	**5**	**0.60**	**0.75**	**0.37**	**4.88**	**5**	**0.75**	**0.06**	**0.25**
repairable module	4.80	5	0.80	1.00	0.45	5.00	5	0.80	0.00	0.00
remanufacturable module	4.80	5	0.80	0.50	0.45	4.50	5	0.60	0.25	1.00
upgradeable module	4.60	5	0.60	0.50	0.55	5.00	5	0.80	0.00	0.00
customizable module	4.00	4	0.20	0.13	0.71	5.00	5	0.80	0.00	0.00
Product as service	**4.04**	**5**	**0.48**	**1.37@**	**0.67**	**4.36**	**5**	**0.56**	**0.30**	**0.48**
multi-functional product-service models	4.80	5	0.80	0.60	0.45	4.80	5	0.80	0.00	0.45
maximized product utilization	4.40	5	0.60	0.63	0.89	4.00	4	0.20	0.00	0.71
high product durability	3.80#	5	0.60	1.15@	1.79@	4.40	5	0.80	0.00	1.34@
enhanced user interaction	3.80#	4	0.00	0.65	0.45	4.60	5	0.60	0.50	0.55
resource-efficient design	3.40#	5	0.40	1.52@	1.82@	4.00	5	0.40	0.50	1.22@
Product life extension	**4.10**	**5**	**0.50**	**0.13**	**0.38**	**4.48**	**5**	**0.70**	**0.25**	**0.29**
extended product lifespan	3.00#	5	0.40	1.13@	1.89@	4.40	5	0.80	0.00	1.34@
ease of repair and refurbishment	4.80	5	0.80	1.03@	0.45	5.00	5	1.00	0.00	0.00
ease of disassembly and reassembly	4.80	5	0.80	0.50	0.45	4.40	5	0.80	0.00	1.34@
product upgradability	4.80	5	0.80	0.50	0.45	4.80	5	0.80	0.00	0.45
reliable and durable components	4.40	4	0.40	0.50	0.55	4.80	5	0.80	0.00	0.45
timeless aesthetic design	3.60#	5	0.40	1.17@	1.67@	3.60#	4	0.20	0.50	1.14@
design for emotional attachment	3.00#	3	0.00	1.22@	1.22@	3.80#	4	0.20	0.50	0.84
accessible product-service system	4.40	4	0.40	1.22@	0.55	5.00	5	1.00	0.00	0.00
Smart material choices	**4.85**	**5**	**0.90**	**0.75**	**0.22**	**4.50**	**5**	**0.55**	**0.00**	**0.18**
easily recyclable materials	5.00	5	1.00	0.66	0.00	4.80	5	0.80	0.00	0.45
reliable and durable materials	4.80	5	0.80	0.13	0.45	4.20	5	0.40	0.50	0.84
restricted or prohibited hazardous materials	5.00	5	1.00	0.13	0.00	4.60	5	0.60	0.50	0.55
biomimetic or biogenic materials	4.60	5	0.80	0.25	0.89	4.40	4	0.40	0.50	0.55

Note: Mo=mode; F.S%=full score ratio; QD= quartile deviation; SD=standard deviation; # indicates low relevance (Mean<4); @ indicates low consensus (QD>1, SD>1)

Divergent interpretations also emerged. Micro-level experts perceived the "Embedded intelligence" strategy as burdensome and complex, whereas meso-level experts valued its potential for system integration and data-driven optimization. This divergence reflects the tension between short-term usability and long-term system

Table 4: Finalized six CDSs and key items by micro and meso level

Micro-Level	Meso-Level
Close loop/ Take back	**Close loop/ Take back**
ease of recycling and maintenance	ease of recycling and maintenance
renewability and reusability	renewability and reusability
product upgradability	product upgradability
ease of disassembly and reassembly	ease of disassembly and reassembly
circular recycling mechanism	circular recycling mechanism
Embedding intelligence	**Embedding intelligence**
N.A.	smart-enabled value-added functions
N.A.	enhanced service experience
N.A.	digitalized smart management
Modularity	**Modularity**
repairable module	repairable module
remanufacturable module	remanufacturable module
upgradeable module	upgradeable module
customizable module	customizable module
Product as service	**Product as service**
multi-functional product services	multi-functional product services
maximized product utilization	maximized product utilization
N.A.	enhanced user interaction
Product life extension	**Product life extension**
N.A.	ease of repair and refurbishment
ease of disassembly and reassembly	N.A.
product upgradability	product upgradability
reliable and durable components	reliable and durable components
N.A.	accessible product-service system
Smart material choices	**Smart material choices**
easily recyclable materials	easily recyclable materials
reliable and durable materials	reliable and durable materials
restricted or prohibited hazardous materials	restricted or prohibited hazardous materials
mono-material use	mono-material use
low-energy consumption materials	low-energy consumption materials

Note：N.A. denotes items removed after expert review due to low relevance or ambiguity.
Source: Compiled by the authors based on primary interview data

optimization, underscoring a need for level-sensitive strategies design. Based on expert input and statistical indicators, redundant, vague, and low-rated items were eliminated (see Table 4). The finalized tools comprised five strategies and 19 key items at the micro level, and six strategies and 24 key items at the meso level—serving as the foundation for cross-level comparative analysis in Stage 2.

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4.2 Stage 2: Survey Implementation and Comparative Analysis

In Stage 2, 60 valid responses were collected—30 from micro level and 30 from meso level with circular design experience. Quantitative analysis was prioritized, using descriptive statistics and independent samples t-tests ($p<0.05$) to examine differences between levels. Qualitative feedback supplemented the interpretation. The "Embedded intelligence" strategy was excluded from cross-level comparison due to conceptual divergence identified in Stage 1 and retained only at the meso level.

No statistically significant difference was found across the five shared strategies, likely due to the prior removal of ambiguous or contested items. However, one item under the "Modularity" strategy — "Repairable module" — was statistically significant (t-value=2.56, $p<0.05$), revealing differing priorities (see Table 5). Micro-level respondents emphasized intuitive handling and ease of use, viewing repairability as a means to enhance user experience. In contrast, meso-level respondents approached modularity from a systemic perspective, highlighting its role in sustaining industrial operations through maintenance, remanufacturing, and upgrades.

Table 5: The comparison of "Modularity" strategies between micro and meso levels

Modularity strategy	Micro-level		Meso-level		t-value	p-value
	Mean	SD	Mean	SD		
repairable module	6.40	0.72	5.71	1.30	2.56	0.01*
remanufacturable module	5.87	1.04	5.58	1.29	0.95	0.34
upgradeable module	5.97	1.07	5.90	1.22	0.22	0.83
customizable module	5.47	1.41	5.52	1.46	-0.14	0.89

Note: $p<0.05$

To facilitate cross-level interpretation, two strategies were selected for comparative analysis (see Table 6): the "Product life extension" strategy received the highest scores (micro: M=6.10; meso: M=6.22), while the "Smart material choices" ranked lowest for the micro level and second-lowest for the meso level (micro: M=5.83; meso: M=5.88). Despite similar ratings, respondents offered diverging interpretations.

Table 6: Statistical comparison of five CDSs between micro and meso levels

Strategy	Micro-level		Meso-level		t-value	p-value
	Mean	SD	Mean	SD		
Close loop/ take back	5.83	0.74	6.09	0.73	-1.37	0.15
Modularity	5.93	0.73	5.69	1.14	0.95	0.56
Product as service	5.93	0.93	6.07	0.74	-0.62	0.83
Product life extension	6.10	0.75	6.22	0.75	-0.60	0.50
Smart material choices	5.83	1.02	5.88	0.71	-0.21	0.63

Source: This study

Micro-level responses emphasized modularity, upgradeability, and ease of use, highlighting that complex or non-intuitive designs could undermine durability and user experience. In contrast, meso-level responses stressed systemic enablers—reverse logistics, after-sales services, embedded monitoring—as critical to sustaining product life. These differences reflect how operational versus infrastructural roles shape evaluation logic. For the "Smart material choices" strategy, micro-level respondents prioritized design feasibility, aesthetics, and user acceptance, yet expressed concerns about limited costs, availability, and material compatibility. Meso-level feedback focused on policy alignment, material standardization, and the application of tools such as life cycle assessment (LCA). While both groups scored this strategy lower—indicating a shared skepticism toward its practical implementation—the underlying rationales diverged, underscoring how system roles influence not only what is prioritized but why.

5. Discussion

This study employed a mixed-methods approach to examine how practitioners at different system levels evaluate CDSs. Survey responses from 60 experienced participants in Stage 2 enabled cross-level comparison of perceptions and priorities. While quantitative data suggested general alignment on the retained strategies, qualitative insights revealed divergent interpretation and implementation logic. The following key findings illustrate how system-level roles shaped strategy evaluation and interpretation:

- Despite generally consistent ratings across the five retained strategies, item-level analysis revealed a significant divergence for "Repairable module," highlighting subtle but meaningful differences.
- Qualitative feedback revealed contrasting interpretations and application logics, particularly evident through the representative strategy analysis.
- Micro-level respondents prioritized usability and operational simplicity, whereas meso-level respondents emphasized systemic enablers such as regulation, standardization, and value-chain integration.

5.1 Divergent Priorities Across System Levels

Stage 1 expert evaluations of six CDSs revealed notable differences in perceived feasibility across system levels. The "Embedding Intelligence" strategy, for example, received strong support from meso-level experts for its potential in data integration, traceability, and platform development. In contrast, micro-level experts flagged concerns about complexity, user burden, and misalignment with core circular principles. Due to low ratings in both appropriateness and alignment, this strategy was excluded from the second-stage micro-level survey. These contrasts reflect the strategy's long-term, system-oriented nature, aligning more with meso-level priorities such as industrial synergies and regional ecosystems. Micro-level actors, by contrast, focus on short-term usability and cost-effectiveness. These findings show that system-level roles influenced early evaluations, exposing distinct priorities and implementation logic.

5.2 Interpretative Gaps Rooted in Practical Experience

While no statistically significant differences emerged in the overall strategy ratings, item-level analysis and qualitative feedback exposed interpretive gaps between system levels. "Repairable module" under the "Modularity" strategy was the only item statistically significant ($p<0.05$), with micro-level respondents prioritizing intuitive disassembly and user convenience, whereas meso level prioritized repair efficiency and system integration. The "representative strategy analysis" (i.e., comparing the highest- and lowest-rated strategies) further illustrated divergent rationales. "Product life extension" received the highest average score across both levels, while "Smart material choices" ranked lowest for the micro level and second-lowest for the meso level—reflecting shared concerns yet differing rationales. Micro-level respondents focused on modularity, upgradeability, and usability, warning that poor design may reduce product lifespan. In contrast, meso-level participants highlighted reverse logistics, after-sales service, and digital monitoring as systemic enablers. Views on material strategies also differed. Micro-level respondents prioritized design feasibility, aesthetics, and production constraints, while meso-level actors emphasized standardization, regulatory tools like LCA, and technological integration. Both levels noted the difficulties sourcing durable, recyclable materials, reflecting implementation barriers in Kirchherr et al. (2017) and Jacobs et al. (2022).

These findings reinforce earlier calls for stratified approaches in CE implementation (Bocken et al., 2016; Kirchherr et al., 2017), showing that role-based interpretations shape strategy uptake and call for differentiated planning. Even when strategies receive similar ratings, practitioners' underlying interpretations vary notably by role and context. This highlights a key insight: consistent scores may mask divergent implementation logics—a critical consideration in developing level-sensitive strategies. Circular design implementation thus requires adaptive, context-aware approaches that bridge expectation gaps and align practices with systemic policy goals. Even when ratings appear consistent, implementation logics diverge across roles and contexts—highlighting the importance of level-sensitive, adaptive design strategies. While this study captured operational-level perspectives, the influence of macro-level policies remains unexplored and warrants further research.

6. Implications and further research

This study developed a level-sensitive circular design framework through a two-stage process involving expert evaluations and practitioner surveys. The final framework comprises five strategies and 19 items for the micro level, and six strategies with 24 items for the meso level, reflecting role-specific priorities and constraints. Although average ratings were broadly aligned, divergent implementation logics emerged, underscoring the limitations of relying solely on score-based generalizations. These findings help address the implementation gap identified in CE literature by empirically revealing how strategy interpretations vary across system levels, shaped by distinct perspectives and contextual barriers. A key limitation is the exclusion of macro-level policy actors, which limits the framework's capacity to reflect governance influences. Future research should incorporate policymaker perspectives to clarify top-down regulatory alignment with operational design. Additional studies may explore cross-sector applicability, trace evolving strategy preferences under technological and contextual changes, and adopt participatory methods to enhance tool adaptability. Such efforts are essential to advancing coordinated, system-aware circular design across scales.

Acknowledgment: The authors gratefully acknowledge the contributions of all participants involved in interviews and survey data collection. This research was supported by the National Science and Technology Council of Taiwan under project number [NSTC 112-2410-H-011-023-MY2].

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