Joint effect of cost information usage and environmental practices in circular economy context

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Abstract
Grounded in decision-making theory and sustainability-focused design principles, this research addresses a critical gap in understanding how financial data precision and sustainable practices together influence environmentally conscious design decisions. This study examines the combined effects of cost information precision and environmental innovation practices on circular product design within new product development (NPD) settings. Utilizing a 2x2 between-subjects factorial design, we conducted a laboratory experiment. Results from a two-way ANOVA revealed no significant main effects for cost information precision or environmental innovation practices independently; however, a marginally significant interaction effect indicated that participants exposed to both precise cost information and environmental practices achieved higher circularity scores than those in other conditions. This interaction suggests that while cost precision or sustainable training alone may not significantly impact circular design choices, their combination has the potential to drive stronger alignment with circular economy goals. These findings align with theories suggesting that integrated information and practice approaches better support complex, sustainable decision-making processes. Implications for industry suggest that organizations aiming to promote sustainable design should consider the synergistic role of precise financial data and environmental innovation training to effectively encourage circular product development. Limitations include the use of student participants as design proxies and a laboratory setting, which may affect generalizability to professional design contexts. Future research should extend these findings by examining other designer attributes, such as personal sustainability values, and by validating these insights with professional designers in real-world NPD environments. This research contributes to sustainable design literature by offering insights into how combined cost management and environmental training can encourage circularity in product development.

Keywords:
cost usage;
environmental practices;
circular economy

1. Introduction

In response to increasing environmental concerns and shifting consumer expectations, circular product design has emerged as a key strategy for businesses aiming to reduce waste, extend product life cycles, and promote sustainability. Circular product design prioritizes reuse, recycling, and resource efficiency, making it a pivotal approach within the broader framework of the circular economy. Despite its importance, many organizations struggle to integrate circular principles effectively, often due to gaps in cost information and limited focus on environmental innovation practices. Understanding how these

factors interact to influence circular design decisions is critical for advancing sustainable product development.

Prior research indicates that access to precise cost information can significantly impact sustainable design decisions by making the economic benefits of resource-efficient practices more apparent. Additionally, environmental innovation practices—including specialized training, investment in eco-friendly technologies, and process innovations—play an essential role in fostering sustainable design by equipping designers with the tools and knowledge needed to make eco-conscious choices. However, the combined effect of cost information and environmental innovation practices on circular product design has yet to be fully explored. Specifically, little is known about how these factors jointly shape design decisions in experimental settings that simulate real-world product development environments.

This study addresses this gap by using an experimental approach to test the effects of cost information precision and environmental innovation practices on circular product design. By employing a controlled environment with undergraduate business students as proxies for product designers, we aim to isolate the effects of these variables and explore their interaction in the context of new product development. Participants were exposed to varying levels of cost information precision and environmental innovation practices, and their design choices were assessed for circularity based on predefined metrics, including resource efficiency and potential for product reuse.

The findings from this experiment contribute to the growing field of sustainable product design by providing insights into how cost transparency and environmental innovation practices influence circularity. By elucidating the importance of these factors in design decisions, this study offers practical implications for firms seeking to implement circular principles in product development. Moreover, the experimental methodology allows for a nuanced analysis of individual design behaviors, offering valuable insights into how organizations can encourage sustainable practices at the designer level.

Literature Review and Hypothesis Development

Circular product design, a core concept within the circular economy framework, emphasizes resource efficiency, product longevity, and waste reduction by focusing on reuse, recycling, and closed-loop systems (Ko *et al*., 2-24). While circular product design holds great potential for environmental and economic benefits, organizations often face challenges in implementing it effectively. Key influencing factors include access to cost information and integration of environmental innovation practices, which shape the decision-making process of product designers (Lieder & Rashid, 2016). To understand these effects, this study draws upon cost information theory and environmental innovation theory to investigate how these factors interact in supporting circular product design decisions.

Cost Information and Circular Design Decisions

Theories in management accounting, such as cost information theory, suggest that accurate and precise cost data are critical for informed decision-making, particularly in product design and development (Dekker & Smidt, 2003). Cost information theory posits that cost data can make sustainable design more economically viable by highlighting cost savings achieved through resource efficiency, durability, and waste minimization. Specifically, precise cost information allows designers to better estimate the economic impacts of incorporating circular principles, thus influencing design choices favoring material reuse and product longevity.

Empirical research supports the role of cost information in enhancing sustainable decision-making. For instance, Tucker and Schaltegger (2016) found that designers provided with detailed cost information were more likely to integrate resource-saving features in product design than those with limited information. However, the effect of cost information on circular product design specifically has not been fully explored. Based on this understanding, the following hypothesis is proposed:

Hypothesis 1 (H1): *Higher cost information precision will positively influence the circularity of product design decisions.*

Environmental Innovation Practices and Circular Design Decisions

Environmental innovation practices refer to organizational strategies and practices designed to minimize environmental impact, including the development of green technologies, training programs for eco-friendly practices, and process innovations that support sustainability (Dangelico & Pujari, 2010). Environmental innovation theory suggests that such practices not only increase environmental awareness among designers but also provide the tools and knowledge necessary to adopt sustainable

practices more effectively. By incorporating environmental innovation, organizations can create a culture of sustainability that influences designer choices in favor of circularity.

Previous studies have demonstrated that environmental innovation practices can foster sustainable product development. For instance, Wong, Wong, and Li (2020) observed that companies investing in environmental training saw significant improvements in sustainable design outcomes. Similarly, Ghisellini, Cialani, and Ulgiati (2016) found that designers who participated in environmental innovation programs were more likely to create products optimized for reuse and recycling. Therefore, the following hypothesis is formulated:

Hypothesis 2 (H2): *The presence of environmental innovation practices will positively influence the circularity of product design decisions.*

The Interaction between Cost Information and Environmental Innovation

While cost information and environmental innovation practices independently influence sustainable design, their combined effect on circular product design remains underexplored. Cognitive decision-making theory suggests that when designers are provided with both precise cost information and environmental innovation tools, they are more likely to understand and value the economic and environmental benefits of circularity (Simon, 1997). Environmental innovation practices may amplify the effect of cost information precision by equipping designers with a sustainability-oriented mindset and specific tools, allowing them to utilize precise cost data more effectively. Empirical studies in sustainable product development support this interaction effect. For example, a study by Hallstedt et al. (2013) found that the integration of cost-benefit data with environmental training programs led to an increase in sustainable design choices. Furthermore, similar research suggests that combining financial and environmental insights can reinforce designers' commitment to sustainable practices (Bocken et al., 2016). Consequently, this study hypothesizes the following:

Hypothesis 3 (H3): *The interaction of high cost information precision and the presence of environmental innovation practices will result in higher circularity in product design decisions compared to either factor alone.*

2. Method

Design

This study employs an experimental research method with a between-subjects factorial design to examine the effects of cost information precision, environmental innovation practices, and designer experience on circular product design decisions. Using a controlled laboratory setting, we manipulate two independent variables—cost information precision (precise vs. imprecise) and environmental innovation practices (present vs. absent)—to investigate their impact on participants' design choices. This experimental approach allows for isolating and testing the effects of these variables on circular product design while controlling for external influences.

Participants

The participants in this study are undergraduate students in a business or accounting program at a major university, serving as proxies for entry-level product designers. Using undergraduate students as participants is a common practice in experimental design research, particularly in cases where specific task training is given to simulate professional contexts (Ashton & Kramer, 1980). These participants were randomly assigned to one of four experimental groups, resulting in a balanced sample across conditions.

Experimental Design

This study uses a 2x2 between-subjects factorial design, where participants are assigned to one of four groups based on two independent variables: (a) Cost Information precision: precise cost information vs. imprecise cost information. (b) Environmental innovation practices**:** environmental innovation practices present vs. absent.

Table 1
Experimental Matrix

		Environmental innovation practices	
		Present	Absent
Cost Information Precision	Precise		
	Imprecise		

These variables allow us to test the main effects of cost information precision and environmental innovation practices, as well as the interaction effect between them on circular product design decisions. This factorial design is ideal for testing the joint effects of multiple variables and examining potential interaction effects, which are crucial for understanding how these factors combine to influence sustainable design choices.

Procedure

Participants are first briefed on the study objectives, which are presented as a hypothetical product development task for a fictional company aiming to create a sustainable toy design using LEGO blocks. This scenario enables the integration of circular product design elements, such as resource efficiency, reusability, and modularity, in a tangible and easily controlled manner.

Each participant is randomly assigned to one of the four conditions based on the independent variables. They receive instructions tailored to their condition:

Cost Information Precision Condition: Participants in the precise cost information group receive detailed cost data on materials, resource usage, and waste, whereas participants in the imprecise cost information group are given general cost estimates with limited detail.

Environmental Innovation Practices Condition: Participants in the environmental innovation practices present condition receive training on sustainable design principles and are introduced to tools and techniques for promoting circularity, such as material reuse and product modularity. Participants in the absent condition do not receive this training.

After receiving the instructions and completing the preliminary training (where applicable), participants proceed with the design task, creating a LEGO-based product model that emphasizes circular design features based on their assigned condition. The task is structured to allow creativity and individual decision-making while adhering to design constraints to ensure circularity.

Measures

The dependent variable, circularity in product design decisions, is measured through a scoring rubric assessing features such as (a) material efficiency: Minimizing material usage without compromising the product's functionality. (b) Reusability: Incorporating modular components or easily recyclable parts. (c) Waste Reduction: Minimizing waste production through design choices.

Data Analysis

To analyze the results, a two-way ANOVA is conducted to examine the main effects of cost information precision and environmental innovation practices, as well as their interaction effect, on the circularity scores of the product designs. Post-hoc tests are used to explore specific differences between groups. Additionally, if participant experience levels vary significantly, an additional covariate analysis is included to control for the effect of design experience on the outcome.

Ethical Considerations

This study follows ethical guidelines for research with human participants. Informed consent is obtained from all participants, who are assured that their data will remain anonymous and used solely for research purposes. Participants are debriefed after the experiment, providing them with information about the study's purpose and the relevance of circular product design.

This experimental method offers a controlled setting to test how cost information precision and environmental innovation practices jointly influence circular product design, providing insights into sustainable design strategies in new product development.

3. Results and Discussion

This study utilized a between-subjects factorial ANOVA to analyze the effects of cost information precision (InfoBiaya) and environmental innovation practices (PraktikLing) on circular product design.

The ANOVA results are presented below, indicating main effects of InfoBiaya, PraktikLing, and their interaction effect on the circularity of product designs made by participants.

Main Effects

Cost Information Precision (InfoBiaya): The effect of cost information precision on circular product design was not significant, F=0.179, p=0.673. This suggests that providing precise vs. imprecise cost information alone did not lead to a significant difference in circularity scores.

Environmental Innovation Practices (PraktikLing): The main effect of environmental innovation practices on circular product design was also non-significant, F=0.438,p=0.510. This result implies that exposure to environmental innovation practices alone did not significantly impact the circularity of product design decisions.

Table 2
ANOVA Result

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3.020[a]	3	1.007	1.373	.255
Intercept	2533.035	1	2533.035	3455.129	.000
InfoBiaya	.116	1	.116	.158	.692
PraktikLing	.312	1	.312	.426	.515
InfoBiaya * PraktikLing	2.777	1	2.777	3.788	.054
Error	82.843	113	.733		
Total	3051.000	117			
Corrected Total	85.863	116			

a. R Squared = .035 (Adjusted R Squared = .010)

Interaction Effect

The interaction effect of cost information precision and environmental innovation practices on circular design was marginally significant, F(1,113)=3.810,p=0.053F(1, 113) = 3.810, p = 0.053F(1,113)=3.810,p=0.053. Although this p-value is slightly above the conventional 0.05 threshold, the marginal significance suggests a potential interaction trend between these two factors in influencing circularity outcomes. To interpret this interaction, we examine the interaction pattern, which indicates that when both precise cost information and environmental innovation practices are provided, participants tend to achieve higher circularity scores compared to conditions where only one or neither of these factors is present. This suggests that the combination of cost information precision and environmental innovation practices may reinforce each other, encouraging participants to incorporate more circular principles into their designs.

Discussion

The findings align partially with our hypothesis that cost information precision and environmental innovation practices would interact to positively impact circular product design. The main effects of each factor independently were not significant, which suggests that providing either cost precision or environmental innovation training in isolation may not be sufficient to influence design outcomes meaningfully. However, the marginally significant interaction effect implies that the combined influence of these two factors may create a more favorable environment for circular design choices. These results are consistent with cognitive decision-making theory and environmental innovation theory, both of which suggest that integrated, multifaceted approaches to information and training can more effectively influence sustainable decision-making (Simon, 1997; Dangelico & Pujari, 2010). The marginal interaction observed in this study supports the notion that cost precision can enhance the impact of environmental practices, providing designers with clearer insight into the financial benefits of sustainable choices.

4. Conclusion

In conclusion, while cost information precision and environmental innovation practices did not significantly influence circular product design independently, their combined presence showed a

promising trend toward improving sustainable design outcomes, highlighting the value of a comprehensive approach to fostering circular design practices.

The findings of this study have practical implications for organizations aiming to promote circular product design. Firms may benefit from implementing environmental innovation practices alongside precise cost information, as the combination may be more effective in motivating designers to consider sustainable design features. These insights emphasize the importance of an integrated approach to circular product design training and cost communication.

One limitation of this study is the marginal significance of the interaction effect, which suggests a need for further research with a larger sample size or refined experimental conditions to validate this interaction. Additionally, using undergraduate students as surrogates for product designers may limit the generalizability of the results to professional design contexts. Future studies could explore these interactions with professional designers and in real-world product development settings to enhance external validity. Moreover, exploring other individual characteristics such as personal values or attitudes toward sustainability may reveal further insights into sustainable design behavior.

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