Circular Design: The Role of Cost Precision and Management Control System

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Abstract
This study investigates the effects of cost information precision and management control systems (MCS) on circular product design, focusing on their potential interplay in fostering sustainable innovation. Despite the increasing emphasis on sustainability in product development, the relationship between cost management practices and circular design remains under-explored. Employing a between-subjects experimental design, undergraduate accounting students served as surrogates for professional designers. Participants were exposed to two levels of cost precision (specific vs. relative) and two types of MCS (diagnostic vs. interactive). The analysis, conducted through ANOVA, revealed a significant interaction effect between cost information precision and MCS on circular design outcomes, approaching statistical significance. Specifically, the combination of specific cost information and interactive MCS showed promise in enhancing participants' circular product design scores. These findings underscore the importance of aligning cost precision with supportive management practices to promote environmentally conscious design choices. This research contributes to the literature on sustainable product development by highlighting the crucial role of management control systems and cost information in facilitating circularity, offering actionable insights for organizations aiming to innovate sustainably. The results pave the way for future investigations into the dynamics of cost information and control systems in driving sustainability initiatives within product development processes.

Article History:

Keywords:
cost information, management control system, circular product design

1. Introduction

As organizations increasingly recognize the urgency of sustainability, many are prioritizing circularity in product design as a key component of their environmental and economic strategies. Circular new product design (NPD) emphasizes reusability, material efficiency, and the minimization of waste, contributing to a product life cycle that supports a circular economy (Ko *et al*., 2024). However, designing products that align with these principles remains challenging, particularly when designers operate under financial constraints and traditional performance metrics. This research investigates how two key organizational elements—cost

information precision and management control systems—affect designers' ability to incorporate circularity in NPD.

Prior studies have shown that access to precise cost information can improve decision-making by clarifying the financial trade-offs of various design options (Horngren et al., 2009). In a circular design context, precise cost data may help designers assess the long-term savings and waste reduction associated with sustainable materials or modular product structures. Similarly, the structure and type of management control systems (MCS) in place play a vital role in guiding employee behavior and encouraging goal alignment. Research on management control theory suggests that systems that emphasize long-term goals and provide sustainable performance metrics can positively influence designers to adopt environmentally conscious design choices (Simons, 1995; Arjaliès & Mundy, 2013).

Despite these insights, the combined impact of cost information and MCS on circular design outcomes remains underexplored. Understanding this relationship is particularly important given the role of designers as decision-makers in the early stages of product development, where choices on materials, modularity, and product life cycle significantly impact circularity. The present study employs an experimental design to examine the interaction between cost information precision (precise vs. imprecise) and the type of management control system (sustainability-focused vs. conventional) on circular product design outcomes.

Using a sample of undergraduate students as proxies for entry-level designers, we simulate a circular NPD task where participants make design decisions with varying degrees of cost information precision and under different MCS conditions. By analyzing how these factors influence circularity in design, this research seeks to contribute to both theory and practice by providing insights into how organizations can support sustainable product innovation. Findings from this study will inform companies aiming to integrate sustainable practices by highlighting the roles of financial data precision and control system structure in promoting circular product design.

Theoretical Framework and Literature Review

This study investigates the impact of **cost information precision** and **management control systems (MCS)** on circular new product design (NPD). Drawing on **decision-making theory** and **management control theory**, this framework explores how providing designers with precise cost data and sustainability-focused MCS can facilitate environmentally conscious design. Through a review of relevant literature, this section highlights how these organizational factors might interact to influence circular design, culminating in hypotheses for testing.

Decision-Making Theory and Cost Information Precision

Decision-making theory suggests that the quality and clarity of information provided to decision-makers significantly influence the choices they make. In NPD, cost information is critical as it informs designers about financial implications of materials, manufacturing processes, and product longevity. Research indicates that **cost information precision**—the accuracy and detail of financial data—can affect design decisions by enabling designers to better understand trade-offs associated with sustainable materials or modularity (Horngren et al., 2009; Locke & Latham, 2002). When cost information is precise, designers may be more

likely to incorporate environmentally friendly components that align with circularity goals, as they can clearly assess potential long-term savings (Preuss, 2005).

However, prior studies have focused more on operational or financial impacts of cost information rather than its influence on sustainable or circular design. This study addresses this gap by examining whether cost information precision encourages designers to prioritize circularity principles, such as material efficiency and reuse potential, over conventional cost-saving approaches.

Hypothesis 1: Cost information precision will positively influence circular product design outcomes, with higher circularity scores observed in conditions with precise cost information compared to imprecise information.

Management Control Systems and Sustainability Goals

Management control systems (MCS) provide the structure within which employees make decisions, aligning their goals with organizational objectives. Traditional MCS often focus on financial metrics and short-term goals, which can conflict with the long-term, systemic thinking required for circular product design (Simons, 1995). In contrast, **sustainability-focused MCS** include performance metrics and incentives that promote environmental goals alongside profitability, supporting designers in making decisions that prioritize long-term impact (Arjaliès & Mundy, 2013).

Studies on sustainability-focused MCS suggest that when organizations provide metrics aligned with sustainability, employees are more likely to adopt behaviors that contribute to environmental goals (Dangelico & Pujari, 2010). In NPD, this may translate to decisions that favor recyclable materials, modular components, or designs that extend product life cycles. While sustainability-oriented MCS have been shown to influence general employee behavior, limited research has tested their specific impact on circularity in product design, particularly in conjunction with cost information precision. Addressing this gap, this study explores whether sustainability-focused MCS can enhance circular design outcomes.

Hypothesis 2: Sustainability-focused management control systems will positively impact circular product design, with higher circularity scores observed in conditions with sustainability-focused MCS compared to conventional MCS.

Interaction of Cost Information Precision and Management Control Systems

While cost information precision and sustainability-focused MCS may each independently influence circular product design, **decision-making theory** suggests an interaction effect, where precise information coupled with aligned control systems amplifies sustainable outcomes (Locke & Latham, 2002). Previous research demonstrates that precise financial data alone may not drive designers toward circularity unless the organizational context, set by MCS, also supports environmental goals (Ghisellini, Cialani, & Ulgiati, 2016). When sustainability-focused MCS are in place, precise cost information can help designers evaluate eco-friendly materials and circular design features not merely as additional costs but as aligned with strategic goals.

This study posits that the presence of both precise cost information and sustainability-focused MCS creates an environment conducive to circular NPD, as the former provides clarity on financial trade-offs while the latter aligns designers' incentives with long-term environmental outcomes.

Hypothesis 3: There will be a significant interaction effect between cost information precision and sustainability-focused MCS, such that the combination of precise cost information and sustainability-focused MCS will lead to the highest circularity scores in product design.

Research Method

This study employs an **experimental research design** with a 2x2 between-subjects factorial structure to examine the effects of cost precision (specific vs. relative) and management control systems (diagnostic vs. interactive) on circular product design. **Undergraduate accounting students** were recruited as participants, serving as surrogates for entry-level product designers, a common approach in experimental studies to approximate the decision-making behaviors of professional designers in controlled settings (Libby et al., 2002).

Participants

A total of 117 undergraduate accounting students participated in the experiment. This sample size is sufficient to detect medium to large effect sizes with acceptable statistical power (Cohen, 1988). Students were chosen due to their familiarity with financial data interpretation, a skill relevant to professional product designers working with cost information in real-world settings. Additionally, accounting students' training in cost and managerial accounting concepts provides a reasonable basis for simulating the cognitive processes that might be involved in professional design roles.

Experimental Design

The experiment utilized a **2x2 factorial design**, manipulating **Cost Precision** (specific vs. relative) and **Management Control System (MCS)** (diagnostic vs. interactive), resulting in four experimental conditions:

1. Specific Cost Precision and Diagnostic MCS
2. Specific Cost Precision and Interactive MCS
3. Relative Cost Precision and Diagnostic MCS
4. Relative Cost Precision and Interactive MCS

Each participant was randomly assigned to one of the four conditions to ensure that assignment was unbiased and that any observed effects were attributable to the experimental manipulations.

Independent Variables

Cost Precision: Participants received either **specific cost information** (detailed cost breakdowns of materials and anticipated cost savings for circular features) or **relative cost information** (general, comparative costs without exact nominal). The specific cost information provided precise, quantitative data to facilitate granular design decisions, while relative cost information offered general cost comparison to mimic a less exact financial assessment.

Management Control System (MCS): Participants were placed under either a **diagnostic** or **interactive MCS** framework, implemented through feedback systems and performance metrics:

1. **Diagnostic MCS** provided participants with minimal feedback focused only on meeting cost targets, emphasizing control and monitoring without room for innovation in circular design.
2. **Interactive MCS** encouraged participants to use creative problem-solving in developing circular design features, providing continuous feedback on environmental goals and sustainability metrics, thus fostering engagement with sustainable design practices.

Experimental Task

Each participant was tasked with designing a prototype for a circular product—specifically, a toy model built from LEGO blocks. This approach allowed for easy measurement of design elements related to circularity, such as modularity, reusability, and material efficiency. Participants received information on circular design principles, emphasizing reusability, recyclability, and minimal waste.

Participants were asked to design their LEGO product within a simulated new product development (NPD) scenario for a hypothetical company. They had access to the cost information and MCS feedback associated with their experimental condition, and they were informed that their design would be evaluated on circularity metrics.

Dependent Variable

The primary dependent variable was **circular product design** score, measured using:

- **Material Intensity**: Use of fewer or sustainable materials.
- **Cost effectiveness**: Total cost per intensity of product.
- **Reusability/Recyclability**: Extent to which components could be reused or recycled.

Procedure

1. **Introduction and Instructions**: Participants were briefed on the study objectives (without revealing specific hypotheses) and given instructions on circular design principles.
2. **Experimental Condition Assignment**: Participants were randomly assigned to one of the four experimental conditions.
3. **Design Task**: Participants engaged in the product design task, utilizing cost information and MCS feedback according to their assigned condition.
4. **Post-Task Questionnaire**: After completing the task, participants filled out a questionnaire assessing their engagement with circular design principles, comprehension of cost information, and perceived effectiveness of MCS feedback.

Data Analysis

Data were analyzed using a **2x2 ANOVA** to examine the main and interaction effects of cost precision and MCS on circular product design. Significant interactions were further analyzed with post-hoc tests to explore the differences between groups in greater detail.

Reliability and Validity

The study employed several measures to ensure **internal validity**:

- Random assignment controlled for selection biases.
- Standardized instructions minimized potential confounding factors across conditions.

Using accounting students as participants provides **external validity** within the context of experimental research, as it reflects early-career decision-making that may generalize to entry-level designers in organizational settings (Ashton & Kramer, 1980).

This experimental method allows for controlled testing of the effects of cost information and MCS on circular design outcomes, contributing to an understanding of how financial and managerial practices can shape sustainable innovation in product development.

Analysis and Results Discussion

The ANOVA analysis was conducted to examine the effects of **Cost Precision** (InfoBiaya), **Management Control System (MCS)** type (SPM), and their interaction on **circular product design** scores. The primary focus of this analysis was to identify whether specific or relative cost information and diagnostic versus interactive MCS independently or interactively influenced the circularity in product design decisions.

Table 1

ANOVA Result

Dependent Variable: Circular

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3.025[a]	3	1.008	1.376	.254
Intercept	2564.506	1	2564.506	3498.268	.000
InfoBiaya	.131	1	.131	.179	.673
SPM	.321	1	.321	.438	.510
InfoBiaya * SPM	2.793	1	2.793	3.810	.053
Error	82.838	113	.733		
Total	3051.000	117			
Corrected Total	85.863	116			

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

Main Effect of Cost Precision (InfoBiaya):

1. The ANOVA result for cost precision showed a non-significant effect on circular product design, F=0.179, p=0.673.

2. This indicates that the level of cost information precision (specific vs. relative) did not significantly impact the circularity of product designs. Designers' performance on circular design features appeared to be independent of the precision of cost data provided.

Main Effect of MCS (SPM):

1. The main effect for MCS type was also non-significant, F=0.438, p=0.510.
2. This suggests that the type of MCS (diagnostic vs. interactive) alone did not significantly influence the circular design scores. The type of control system feedback given to designers did not independently lead to differences in circular product outcomes.

Interaction Effect between Cost Precision and MCS (InfoBiaya * SPM):

1. The interaction between cost precision and MCS type approached significance, F=3.810, p=0.053, suggesting a trend where the combination of specific cost information and interactive MCS might enhance circular product design. However, since the p-value slightly exceeds the conventional significance threshold of 0.05, the interaction effect cannot be confirmed with high confidence in this analysis.
2. Although this result does not meet strict significance levels, it suggests a potential relationship worth exploring in future studies or with a larger sample size. The data imply that when specific cost data is coupled with interactive MCS, designers may feel more supported in making environmentally conscious choices in product design, aligning cost considerations with sustainability goals.

Discussion of Results

The findings suggest that neither cost information precision nor MCS type alone was sufficient to drive significant changes in circular product design among participants. However, the marginally significant interaction effect between cost precision and MCS provides some insight into how these elements might work together to support circular design. Specifically, **specific cost information combined with an interactive MCS** might create an environment where designers are better able to integrate circular principles, as they receive both clear cost information and continuous feedback encouraging sustainable choices.

These findings are partially consistent with **decision-making theory**, which posits that the alignment of detailed information and supportive controls can facilitate goal-congruent decisions. When designers receive specific cost information, they may better understand the trade-offs associated with circular features, particularly when interactive MCS reinforces sustainability as a priority.

Implications

This study highlights the importance of **combining precise financial data with supportive management systems** to foster sustainable design. While precise cost information alone may not influence circular design, an interactive MCS may guide designers to leverage this data effectively by aligning it with circularity objectives. The trend observed here aligns with research suggesting that MCS which are interactive—encouraging ongoing learning and feedback—can motivate employees to pursue long-term organizational goals, such as sustainability (Simons, 1995).

Limitations and Future Directions

The findings are limited by the sample size and the marginal significance of the interaction effect. Future research could benefit from larger sample sizes to confirm these trends. Additionally, extending the study to professional designers may offer insights into how these findings generalize beyond the student sample used here. Further research could also investigate other factors, such as **designer motivation** or **organizational culture**, to better understand how these variables may interact with cost information and MCS in promoting sustainable product design.

This research contributes to the understanding of **how cost information and control systems interact** in driving circularity in product development, offering a potential pathway for firms to enhance sustainable innovation by structuring both financial data and MCS to support environmental goals.

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