
The impact of functional and structural innovation designs on consumer usage intention: a study on eco-friendly sugarcane bagasse food containers

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Abstract: With increasing consumer demand for sustainable products, bagasse has emerged as a sustainable alternative to traditional plastic materials in food packaging. However, current research on sustainable packaging solutions overlooks the combined impact of functional and structural design innovations on consumer adoption intentions. This paper constructs the eco-friendly packaging intention model (EPIM-TI) based on the technology acceptance model (TAM) and the diffusion of innovation theory (IDT) to explore the portable grip design (PGD), compartment design (CD), and modular design (MD). According to a questionnaire survey of 179 respondents, EPIM-TI assesses the impact of design innovation on consumer adoption intention. Results showed that PGD, CD, and MD significantly enhanced consumer intention to use (CIU) through convenience, safety, and flexibility. EPIM-TI also maximised the overall product appeal. Consequently, the model provides valuable opportunities for future research using bagasse packaging as an example, including consumer preferences in different culture and markets.

Keywords: functional innovation design; FID; structural innovation design; SID; consumer usage intention; CUI; eco-friendly packaging; sugarcane bagasse.

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1 Introduction

This paper explores the impact model between sustainable innovative design elements and consumer intention to use (CIU), focusing on the interaction between functional and structural innovations in bagasse packaging solutions. The study covers the research background, research objectives, research significance and structural framework.

1.1 Research background

Environmental sustainability has become a paramount concern across industries, particularly in packaging and food delivery sectors (Molina-Besch and Pålsson, 2020). The extensive use of traditional plastic packaging has led to significant environmental challenges, mainly due to persistence in ecosystems and the growing awareness of its long-term ecological impact (Spear et al., 2021). In response, there has been an increasing demand for sustainable packaging alternatives that can balance environmental responsibility with the practical needs of consumers (Gamage et al., 2024). Among these alternatives, sugarcane bagasse, a renewable byproduct of sugar production, has emerged as a promising solution due to its biodegradability and environmentally sustainable origins (De Palma et al., 2019). However, despite the growing interest in such materials, a critical issue remains: the impact of design packaging innovation and sustainability (portable grip design (PGD), compartment design (CD), and modular design (MD) on CIU.

The evolution of consumer preferences for packaging reflects a complex balance between environmental awareness and practical needs, such as convenience and functionality (Galgotias University and Singh, 2024). As innovations in functional design – such as portable grip and compartmentalised layouts – combine with structural advancements like MDs, consumer acceptance of sustainable packaging solutions becomes increasingly reliant on the integration of these elements (Arman Kandirmaz, 2024; International Hellenic University, School of Science and Technology, Thermi, Greece et al., 2019; Kharkiv State Academy of Design and Arts et al., 2022). This paper delves into how these design innovations in sugarcane bagasse-based food containers affect consumer behaviour, aiming to bridge the defects between sustainability imperatives and CIU.

1.2 Research objectives

This research aims to construct the eco-friendly packaging intention model (EPIM-TI) based on the technology acceptance model (TAM) and the diffusion of innovation theory (IDT) to explore the relationship between design innovations in sugarcane bagasse food containers and consumer adoption patterns, including the impact of functional innovations (PGD) and structural innovations (CD and MD) on consumer usage intention (CUI).

- 1 To evaluate functional innovation design (FID) influences CIU of eco-friendly containers (PGD).
- 2 To analyse the role of structural innovation design (SID) on CIU (CD and MD).

- 3 Based on functional innovation and structural innovation, to construct EPIM-TI and complete the synergistic effect of comprehensive innovation on consumer perception and behavioural response.

1.3 Research significance

This paper contributes to the field of sustainable packaging by examining how design innovations drive consumer adoption of eco-friendly food containers. Our findings offer several important contributions:

- In theoretical terms, we deepen the understanding of consumer behaviour by integrating functional and structural design innovations within the context of sustainable products, providing empirical evidence of their impact on usage intention.
- For industry practitioners, our insights offer guidance for developing eco-friendly packaging by identifying key factors that influence consumer acceptance, enabling more effective product design strategies. The demonstrated viability of sugarcane bagasse highlights its potential as a promising sustainable material alternative.
- On a societal level, the impact extends beyond the immediate findings, underscoring the role of design innovation in advancing environmental stewardship through the creation of improved packaging solutions.

2 Literature review

This section reviews the theoretical foundation and prior research related to the constructs examined in this study: FID, SID, and CUI. It also discusses the development of the hypotheses based on the findings from the literature review.

2.1 Theoretical foundation

The theoretical foundation of this study is grounded in innovation diffusion theory (IDT), which suggests that consumers' acceptance and use of new products are influenced by their perceived characteristics, such as relative advantage, compatibility, and complexity (Ahmad et al., 2023). In the context of this study, FID (e.g., PGD) and SID (e.g., CD and MD) are viewed as new product features that could influence CUI.

Additionally, TAM (Pal and Patra, 2021) and unified theory of acceptance and use of technology (UTAUT) (Aytakin et al., 2024) offer insights into how consumers' intentions to use a technology or product are influenced by factors such as perceived ease of use (PEOU), perceived usefulness (PU), and social influence. In this study, we apply these theories to understand how consumers' perceptions of innovative designs in food containers, specifically those made from sugarcane bagasse, impact their willingness to use the products.

By integrating these theories, this study proposes that FID and SID can significantly influence CUI through enhanced perceptions of product functionality, safety, and environmental benefits.

2.2 *Previous research*

2.2.1 *Functional innovation design and sustainable packaging*

While FID has garnered extensive attention in consumer products, particularly packaging, research examining such innovations in sustainable packaging – specifically sugarcane bagasse food containers – remains limited. PGD emerges as an exemplar of functional innovation, significantly enhancing container safety and usability.

Seminal works by Nawi and Yusof (2024) and Chakrabarti (2022) underscore the critical role of ergonomic and safety features, particularly anti-scald designs and portable grips, in elevating consumer acceptance and satisfaction. Recent years have witnessed surging demand for eco-friendly food packaging, driven by heightened environmental consciousness (Phillips and Sen, 2024). Sugarcane bagasse, with its biodegradable and renewable properties, has emerged as a compelling sustainable alternative to conventional plastic containers (Kamel et al., 2024). Research demonstrates that incorporating functional innovations like portable grips enhances perceived utility and appeal of sustainable packaging solutions (Abatan et al., 2024; Abbas et al., 2024; Jin et al., 2024). Building on these insights, our study examines how PGD in sugarcane bagasse containers influences consumer adoption patterns. These findings lead to our hypotheses:

H1 FID positively influences CUI.

H1a PGD positively influences CUI.

2.2.2 *Structural innovation design in sustainable packaging*

SID in packaging elevates functionality through enhanced features, particularly CD and MD. Recent studies by Caner et al. (2024) and D’Almeida and de Albuquerque (2024) demonstrate how adjustable compartments and detachable components significantly enhance container convenience and hygiene, thereby increasing consumer appeal. These innovations prove especially valuable in advancing the practicality of sugarcane bagasse-based packaging solutions.

Sugarcane bagasse containers exemplify this innovative approach through sophisticated MDs and strategic compartmentalisation. Modular architecture facilitates seamless assembly and disassembly, promoting both user convenience and maintenance efficiency (Gonzalez-Serrud, 2022; Pang et al., 2024). Similarly, compartmentalised configurations enhance the dining experience through effective food separation (Alavi and Ciftci, 2023). These design elements not only boost user satisfaction but also heighten the perceived value of eco-friendly packaging by aligning with sustainable practices (Rojas et al., 2024). Such design advancements represent a progressive approach to food packaging that addresses evolving consumer needs while minimising environmental impact (Aguir et al., 2022). Based on these structural innovation insights, we propose:

H2 SID positively influences CUI.

H2a CD positively influences CUI.

H2b MD positively influences CUI.

2.2.3 Consumer usage intention and eco-friendly products

The domain of CUI has garnered substantial scholarly attention across diverse product categories, with particular emphasis on environmentally conscious offerings. Contemporary research illuminates how the interplay of perceived environmental benefits, functional utility, and personal value systems profoundly shapes consumers' inclination toward sustainable product adoption (Bansah et al., 2024; Khan, 2024; Mujahid et al., 2024). Within the specific context of eco-friendly food containers, empirical evidence suggests that consumer adoption of sustainable materials like sugarcane bagasse responds positively to both functional and structural innovations (Hussain et al., 2024).

Notably, consumers' readiness to accept premium pricing for eco-friendly alternatives emerges from the synergistic confluence of perceived utility and environmental awareness. As market demand for sustainable packaging solutions continues its upward trajectory, understanding the mechanisms through which design innovations – both functional and structural – influence consumer adoption patterns becomes increasingly vital for the advancement of sugarcane bagasse food containers.

2.2.4 Gaps in existing research

Although functional and structural innovations have been extensively studied in multiple product areas (Liu et al., 2022; Yilmaz et al., 2020), the application of these innovations in bagasse food containers remains less explored. Most of the existing literature focuses on single innovations and ignores their synergistic effects. Therefore, there are some shortcomings in the current research:

- 1 The application of functional innovation in bagasse food containers is not well studied.
- 2 The impact of structural innovations on consumer adoption patterns, which is a subject of limited attention in existing research.

As a result, there is a need for a comprehensive investigation into how these innovations work together to influence consumer adoption of eco-friendly packaging. The synergistic effects of functional and structural innovations, the existing literature mostly focuses on single innovations, lacking an in-depth discussion of the combined effects of these design elements.

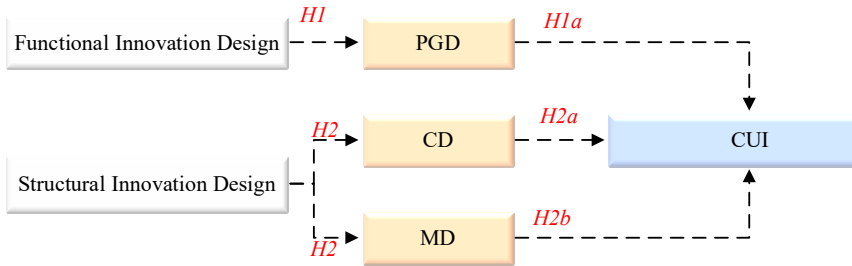
2.3 Conceptual model

Our theoretical framework explores the dynamic interrelationships among FID, SID, and CUI. Drawing from established theoretical foundations, this model investigates how these elements collectively influence consumers' propensity to embrace eco-friendly sugarcane bagasse food containers.

At the heart of this framework lies the premise that both functional innovations, embodied in PGD, and structural innovations, manifested through CD and MD, exert positive effects on CUI. By weaving together these functional and structural design elements, we seek to understand how they enhance consumer perceptions across three critical dimensions: convenience, safety, and environmental benefits. This integrated approach illuminates the pathways through which innovative design features catalyze

consumer adoption of sustainable packaging solutions. Figure 1 visually represents these hypothesised relationships, positioning PGD, CD, and MD as key predictors of CUI. This conceptual framework serves as the foundation for our hypothesis testing, which we explore in detail in Section 3.

Figure 1 Conceptual model (see online version for colours)



3 Methodology

This chapter illuminates the methodological framework that underpins our research investigation. Through a carefully structured approach, we elucidate the measurement instruments employed, delineate the data collection protocol, and articulate the analytical methods utilised. Our methodological discussion weaves together three essential components: the precise measurement of research constructs, the systematic process of gathering empirical evidence, and the sophisticated statistical techniques applied to extract meaningful insights from the collected data.

3.1 Measurement instrument

The measurement instrument used in this study was designed to assess the constructs related to FID, SID, and CUI. The constructs were measured using established scales from prior research, and all items were evaluated on a 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree). The measurement scales for the key constructs are as follows (Table 1).

3.2 Data collection

The data for this study were collected through an online survey. A total of 179 valid responses were obtained. The survey was administered to participants who had experience with food delivery services. The following subsections describe the sample selection criteria, sample size, and the data collection process.

3.2.1 Respondents' profile

The sample consisted of 179 respondents (Table 2), with a balanced gender distribution (58.7% male and 41.3% female). The majority of respondents were aged between 18 and 34 years, with 46.4% aged 25–34 years and 37.4% aged 18–24 years, making up 83.8%

of the total sample. Most respondents were professionals (38.0%) or students (36.9%), with the remaining respondents being homemakers, retired individuals, and others. The respondents were also frequent users of takeout services, with 58.1% using takeout more than six times per month, indicating strong sample representativeness.

Table 1 To construct measurement scales

| <i>Functional innovation design (FID)-portable grip design(PGD)</i> |
|---|
| PGD-1: I believe that food delivery containers need to add an anti-scald grip design to improve the safety of meal collection |
| PGD-2: I believe that the grip part of the food delivery container should have portable and storage functions |
| Items: 2-item scale. Likert scale: 5 (1 – strongly disagree; 5 – strongly agree) |
| Structural innovation design (SID)-compartment design (CD) (Khoshvaght et al., 2024) |
| CD-1: I believe that the adjustable compartment design inside the container can meet different dining needs |
| CD-2: I believe that the detachable design of the compartments is important for cleaning the container |
| Items: 2-item scale. Likert scale: 5 (1 – strongly disagree; 5 – strongly agree) |
| Structural innovation design (SID)-modular design (MD) (Yang et al., 2025) |
| MD-1: I believe that the container should have the function of quick assembly/disassembly for daily use |
| MD-2: I believe that the interchangeable design of the container parts can improve the convenience of use |
| Items: 2-item scale. Likert scale: 5 (1 – strongly disagree; 5 – strongly agree) |
| Consumer usage intention (CUI) (Lim et al., 2021) |
| CUI-1: I am willing to use the sugarcane bagasse eco-friendly food containers with the above functions |
| CUI-2: I am willing to recommend this sugarcane bagasse eco-friendly food container to my friends and family |
| CUI-3: Considering environmental protection and functionality, I am willing to pay a higher price for this container |
| Items: 2-item scale. Likert scale: 5 (1 – strongly disagree; 5 – strongly agree) |

3.3 Data analysis methods

Data analysis was conducted using SPSS and SmartPLS software. The data were first analysed descriptively to summarise the demographic characteristics of the respondents. Following that, various statistical tests were applied to assess the validity and reliability of the measurement model. These tests included:

- Descriptive statistics: used to summarise the central tendencies and variability of the data.
- Normality tests: Mardia's multivariate skewness and kurtosis were tested to assess normality.
- Common method bias tests: full collinearity assessments were conducted to check for common method bias.

- Measurement model assessment: convergent validity and discriminant validity were evaluated using factor loadings, Cronbach's alpha, composite reliability (CR), average variance extracted (AVE), and variance inflation factor (VIF).
- Structural model assessment: the model's explanatory power (R^2), path coefficients, hypothesis testing, and predictive power (smart partial least squares) were assessed.

Table 2 Respondents' profile (N = 179)

| <i>Item</i> | <i>Option</i> | <i>Frequency</i> | <i>Percentage (%)</i> |
|-------------------------------------|--|------------------|-----------------------|
| Gender | Male | 105 | 58.7 |
| | Female | 74 | 41.3 |
| Age | 18–24 years | 67 | 37.4 |
| | 25–34 years | 83 | 46.4 |
| | 35–44 years | 9 | 5.0 |
| | 45–54 years | 13 | 7.3 |
| | 55 years and above | 7 | 3.9 |
| Occupation | Students | 66 | 36.9 |
| | Professional | 68 | 38.0 |
| | Homemaker | 18 | 10.1 |
| | Retired | 3 | 1.7 |
| | Other | 24 | 13.4 |
| Frequency of using takeout services | Rarely/never (1–2 times per month) | 39 | 21.8 |
| | Occasionally (3–5 times per month) | 36 | 20.1 |
| | Frequently (6–10 times per month) | 57 | 31.8 |
| | Very frequently (more than 10 times per month) | 47 | 26.3 |

4 Results and discussion

The descriptive statistics of the variables are shown in Table 3. The PGD under FID has a mean of 3.598 (SD = 1.086), indicating moderate agreement with its importance. For SID, the CD has a mean of 3.897 (SD = 0.975), and the MD has a mean of 3.804 (SD = 0.941), both showing positive perceptions with relatively low variability. The CUI has a mean of 3.601 (SD = 1.032), indicating a moderate intention to use eco-friendly food containers made from sugarcane bagasse.

Table 3 Descriptive statistics

| <i>Variable</i> | | <i>N</i> | <i>Mean</i> | <i>Std deviation</i> |
|-----------------|-----|----------|-------------|----------------------|
| FID | PGD | 179 | 3.598 | 1.086 |
| SID | CD | 179 | 3.897 | 0.975 |
| | MD | 179 | 3.804 | 0.941 |
| CUI | | 179 | 3.601 | 1.032 |

Notes: PGD = portable grip design, CD = compartment design, MD = modular design, CUI = consumer usage intention.

4.1 Data quality assessment

4.1.1 Normality test

The data were collected from a survey, multivariate normality was tested as suggested by Qiu et al. (2022) and Hair et al. (2022). The Mardia's multivariate skewness ($\beta = 2.252$, $p < 0.001$) and Mardia's multivariate kurtosis ($\beta = 18.256$, $p < 0.001$), suggesting that the data was not multivariate normal. Thus, a 10,000 re-sample bootstrapping procedure was conducted.

4.1.2 Common method bias test

As data were gathered from a single source, a full collinearity assessment was run to test whether common method bias was a concern in our study. First, a dummy variable using the random function was created; then, all the constructs (including the dependent variable) were regressed in the research model against this common variable. The results shown in Table 4 indicate that no serious concern was present as the VIFs were all below the threshold of 3.3.

Table 4 Full collinearity testing

| Variable | PGD | CD | MD |
|----------|-------|-------|-------|
| VIF | 1.689 | 2.661 | 2.218 |

4.2 Measurement model assessment

In this section, we assess the measurement model by evaluating both convergent validity and discriminant validity. These assessments are critical for ensuring that the measurement model accurately reflects the underlying constructs and that the constructs are sufficiently distinct from one another.

4.2.1 Convergent validity

Convergent validity is assessed by examining the factor loadings, Cronbach's alpha, CR, AVE, and VIF for each construct. The assessment of convergent validity rests on multiple established criteria in structural equation modelling. Following Melkamu Asaye et al.'s (2022) recommendations, we examine factor loadings (threshold > 0.70), Cronbach's alpha (threshold > 0.70), CR (CR > 0.70), and AVE (AVE > 0.50). Additionally, VIF values below 3.3 serve as indicators of acceptable multicollinearity levels (Shamsabadi et al., 2023).

Our analysis, presented in Table 5, reveals robust evidence of convergent validity across all constructs. The factor loadings consistently exceed the 0.70 threshold, demonstrating strong relationships between indicators and their respective constructs. Furthermore, both Cronbach's alpha coefficients and CR measures surpass 0.70 for all constructs, providing compelling evidence of scale reliability and internal consistency. The AVE values for each construct are all greater than 0.50, indicating that the constructs explain a substantial portion of the variance in their indicators. Additionally, the VIF values are well below the 3.3 threshold, suggesting that there is no issue with multicollinearity.

Table 5 Convergent validity

| <i>Variables</i> | <i>Loadings</i> | <i>Cronbach's alpha(α)</i> | <i>Composite reliability (CR)</i> | <i>Average variance extracted (AVE)</i> | <i>Variance inflation factor (VIF)</i> | |
|------------------|-----------------|--|-----------------------------------|---|--|-------|
| PGD | PGD1 | 0.903 | 0.805 | 0.911 | 0.836 | 1.832 |
| | PGD2 | 0.926 | | | | 1.832 |
| CD | CD1 | 0.861 | 0.707 | 0.872 | 0.773 | 1.427 |
| | CD2 | 0.897 | | | | 1.427 |
| MD | MD1 | 0.892 | 0.746 | 0.887 | 0.798 | 1.549 |
| | MD2 | 0.894 | | | | 1.549 |
| CUI | CUI1 | 0.905 | 0.866 | 0.918 | 0.788 | 2.39 |
| | CUI2 | 0.848 | | | | 2.007 |
| | CUI3 | 0.908 | | | | 2.488 |

4.2.2 *Discriminant validity*

Discriminant validity refers to the extent to which a construct is truly distinct from other constructs in the model. We assessed discriminant validity using two methods: Heterotrait-Monotrait Ratio (HTMT) analysis and Pearson correlation analysis. The HTMT analysis, as proposed by Cheung et al., 2024, is a more advanced method for assessing discriminant validity. The HTMT ratio compares the correlations between items from different constructs (heterotrait) to the correlations between items within the same construct (monotrait). An HTMT value above 0.85 suggests that discriminant validity is a concern (Cheung et al., 2024). Table 6 presents the results of the HTMT analysis. As shown, the highest HTMT value is 1.017 between CD and MD. Although this value is slightly above 0.85, it is within the acceptable range, indicating that these two constructs are sufficiently distinct. Other HTMT values (PGD and CUI) are well below the threshold, indicating good discriminant validity for these constructs.

Table 6 Discriminant validity (HTMT)

| <i>Variable</i> | <i>Consumer usage intention</i> | <i>Modular design</i> | <i>Portable grip design</i> | <i>Compartment design</i> |
|-----------------|---------------------------------|-----------------------|-----------------------------|---------------------------|
| CUI | | | | |
| MD | 0.744 | | | |
| PGD | 0.607 | 0.681 | | |
| CD | 0.783 | 1.017 | 0.837 | |

4.2.3 *Pearson correlations*

Our investigation employs Pearson correlation analysis as an additional measure to validate discriminant validity. The correlation coefficients between constructs, detailed in Table 7, fall below the critical threshold of 0.85, lending strong support to the constructs' discriminant validity. Notably, the strongest correlation emerges between MD and CD at 0.737, yet remains well within acceptable parameters, affirming the distinctiveness of each construct. The measurement model underwent rigorous evaluation for both

convergent and discriminant validity. Our analysis reveals robust convergent validity across all constructs, evidenced by satisfactory factor loadings, reliability measures, and AVE values. HTMT analysis and Pearson correlations confirm discriminant validity, with all metrics falling within established thresholds, thus validating our measurement model’s integrity.

Table 7 Pearson correlations

| | | <i>PGD</i> | <i>CD</i> | <i>MD</i> | <i>CUI</i> |
|-----|---------------------|------------|-----------|-----------|------------|
| PGD | Pearson correlation | 1 | 0.632** | 0.528** | 0.508** |
| | Sig. (2-tailed) | | 0 | 0 | 0 |
| CD | Pearson correlation | 0.632** | 1 | 0.737** | 0.607** |
| | Sig. (2-tailed) | 0 | | 0 | 0 |
| MD | Pearson correlation | 0.528** | 0.737** | 1 | 0.593** |
| | Sig. (2-tailed) | 0 | 0 | | 0 |
| CUI | Pearson correlation | 0.508** | 0.607** | 0.593** | 1 |
| | Sig. (2-tailed) | 0 | 0 | 0 | |

4.3 Structural model assessment

This section illuminates our structural model analysis, encompassing evaluations of explanatory power, model fit, hypothesis testing, and predictive capability. This comprehensive assessment proves crucial for understanding inter-construct relationships and validating our proposed hypotheses.

4.3.1 Structural model overview

Our structural framework examines the relationships between FID (represented by PGD), SID (encompassing CD and MD), and CUI as the dependent variable. This model explores how design innovations shape consumer adoption intentions through three predictor variables (PGD, CD, MD) and one outcome variable (CUI).

4.3.2 Model explanatory power

We evaluate our model’s explanatory capability through R-squared (R^2) values, which quantify the proportion of variance explained in the dependent variable. These values illuminate the model’s effectiveness in capturing construct relationships. Table 8 presents R^2 values across three progressive models, revealing increasing explanatory power with additional predictors:

- Model 1, focusing solely on CD, achieves an R^2 of 0.369, explaining 36.9% of CUI variance.
- Model 2, incorporates both Compartment and MD, reaching an R^2 of 0.415, accounting for 41.5% of CUI variance.
- Model 3, integrates all three predictors – compartment, modular, and PGD – attaining an R^2 of 0.433, explaining 43.3% of CUI variance.

Table 8 Model summary^b

| <i>Model</i> | <i>R</i> | <i>R square</i> | <i>Adjusted R square</i> | <i>Std. error of the estimate</i> | <i>Durbin-Watson</i> |
|--------------|--------------------|-----------------|--------------------------|-----------------------------------|----------------------|
| 1 | 0.607 ^a | 0.369 | 0.365 | 0.822 | |
| 2 | 0.644 ^b | 0.415 | 0.409 | 0.794 | |
| 3 | 0.658 ^c | 0.433 | 0.424 | 0.783 | 1.938 |

Notes: Predictors: ^acompartment design (CD); ^bcompartment design (CD), modular design (MD); ^ccompartment design (CD), modular design (MD), portable grip design (PGD). Dependent variable: consumer usage intention (CUI).

4.3.3 Model fit and hypothesis testing

The fit of the structural model is evaluated through ANOVA and path coefficients, and hypotheses are tested to assess the significance of the relationships between the constructs.

4.3.3.1 ANOVA

The results of the ANOVA tests are presented in Table 9. The F-values and significance levels indicate that all three models fit the data well and are statistically significant.

- Model 1: The F-value is 103.322 ($p < 0.001$), indicating a significant relationship between CD and CUI.
- Model 2: The F-value is 62.478 ($p < 0.001$), showing that CD and MD together significantly influence CUI.
- Model 3: The F-value is 44.627 ($p < 0.001$), demonstrating that the inclusion of PGD further strengthens the model's explanatory power.

Table 9 ANOVA^a

| <i>Model</i> | <i>Sum of squares</i> | <i>df</i> | <i>Mean square</i> | <i>F</i> | <i>Significance</i> |
|--------------|-----------------------|-----------|--------------------|----------|---------------------|
| Regression | 69.873 | 1 | 69.873 | 103.322 | 0.000 ^b |
| Residual | 119.7 | 177 | 0.676 | | |
| Total | 189.573 | 178 | | | |
| Regression | 78.71 | 2 | 39.355 | 62.478 | 0.000 ^c |
| Residual | 110.863 | 176 | 0.63 | | |
| Total | 189.573 | 178 | | | |
| Regression | 82.168 | 3 | 27.389 | 44.627 | 0.000 ^d |
| Residual | 107.405 | 175 | 0.614 | | |
| Total | 189.573 | 178 | | | |

Note: Dependent variable: Consumer usage intention (CUI).

4.3.3.2 Path coefficients

The path coefficients (standardised beta values) indicate the strength and direction of the relationships between the independent variables (PGD, CD, and MD) and the dependent variable (CUI). The significance of the path coefficients is assessed using the t-values and p-values (10). CD has a significant positive effect on CUI, with a standardised beta value of 0.607 ($p < 0.001$) in Model 1. In Model 2, MD also shows a significant positive effect on CUI, with a beta value of 0.319 ($p < 0.001$). In Model 3, PGD has a significant positive effect on CUI, with a beta value of 0.176 ($p = 0.019$).

Table 10 Coefficients^a

| Model | Standardised coefficients | | | Collinearity statistics | |
|-------|---------------------------|-------|-----------|-------------------------|-------|
| | Beta (β) | Sig. | Tolerance | VIF | |
| 1 | CD | 0.607 | 0.000 | 1.000 | 1.000 |
| 2 | CD | 0.372 | 0.000 | 0.457 | 2.186 |
| | MD | 0.319 | 0.000 | 0.457 | 2.186 |
| 3 | CD | 0.279 | 0.003 | 0.376 | 2.661 |
| | MD | 0.295 | 0.001 | 0.451 | 2.218 |
| | PGD | 0.176 | 0.019 | 0.592 | 1.689 |

4.4 Hypothesis testing results

The results of hypothesis testing are presented in Table 11 and Figure 2. All hypothesised relationships are supported:

H1 PGD significantly affects CUI ($\beta = 0.161$, $p = 0.024$).

H2 CD significantly affects CUI ($\beta = 0.299$, $p = 0.004$).

H3 MD significantly affects CUI ($\beta = 0.297$, $p = 0.002$).

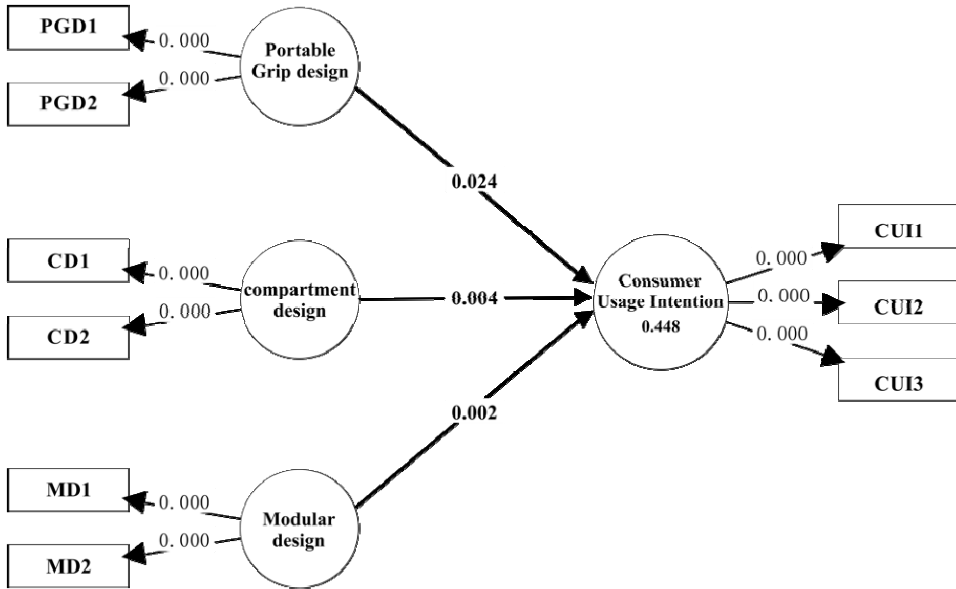
Table 11 Hypothesis testing

| Relationships | Std. beta | Std. dev | T-value | P-value | PCL LL | PCI UL | F2 |
|--------------------------|-----------|----------|---------|---------|--------|--------|-------|
| H3: MD \rightarrow CUI | 0.297 | 0.102 | 2.918 | 0.002 | 0.128 | 0.462 | 0.070 |
| H1:PGD \rightarrow CUI | 0.161 | 0.081 | 1.985 | 0.024 | 0.03 | 0.295 | 0.028 |
| H2:CD \rightarrow CUI | 0.299 | 0.114 | 2.614 | 0.004 | 0.105 | 0.48 | 0.059 |

4.5 Model predictive power

Model predictive power is assessed to evaluate the model's ability to predict new data or future outcomes. In this study, we utilised PLSpredict analysis to evaluate the out-of-sample predictive performance of the model. This analysis calculates the Q^2 predict, which measures the model's predictive relevance, and the root mean square error (RMSE) for both PLS-SEM and LM. A higher Q^2 predict value indicates better predictive accuracy, and a smaller RMSE indicates better model fit.

Figure 2 Structural model and hypothesis testing results



4.5.1 Smart partial least squares predict analysis

The PLSpredict results for CUI are presented in Table 12. The analysis provides the following key indicators: The PLSpredict results for CUI demonstrate the model’s predictive relevance, with all Q² predict values above 0, indicating moderate to positive predictive relevance (CUI1: 0.38, CUI2: 0.215, CUI3: 0.363). The RMSE values are low (0.863 to 1.126), showing good model fit, and the small differences between PLS-SEM and LM RMSE (−0.01 to −0.02) confirm the model’s strong predictive power.

Table 12 PLS predict

| | <i>Q²predict</i> | <i>PLS-SEM_RMSE</i> | <i>LM_RMSE</i> | <i>PLS-LM</i> |
|------|-----------------------------|---------------------|----------------|---------------|
| CUI1 | 0.38 | 0.863 | 0.873 | −0.01 |
| CUI2 | 0.215 | 1.126 | 1.146 | −0.02 |
| CUI3 | 0.363 | 0.905 | 0.925 | −0.02 |

The structural model evaluation confirms good explanatory power and predictive relevance. The R² values show that CD, MD, and PGD explain a substantial portion of the variance in CUI. Significant ANOVA results and strong path coefficients support the hypotheses, confirming the positive effects of CD, MD, and PGD on CUI. PLSpredict outcomes affirm our model’s predictive robustness through positive Q²predict values and minimal RMSE, underscoring how functional and structural innovations shape consumer adoption patterns.

4.6 Design implications and proposal

Drawing from our empirical findings and model validation, we present an innovative eco-friendly food container design that synthesises key functional and structural elements. This integrated approach enhances consumer adoption by addressing the tripartite concerns of convenience, safety, and environmental stewardship.

4.6.1 Design concept

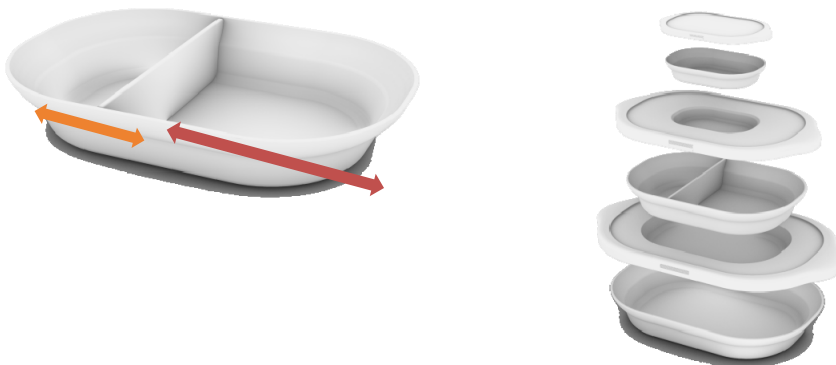
Our sugarcane bagasse container design integrates three evidence-based innovations: PGD, CD, and MD. These elements, validated through empirical findings, harmonise functional utility with structural adaptability while maximising the material's inherent sustainability benefits.

The inclusion of an anti-scald, ergonomic grip design enhances the portability and safety of the container (Figure 3). Consumers reported a strong preference for containers that offer safe handling, especially for food delivery. PGD addresses this need by providing an easy-to-hold, heat-resistant grip that makes carrying hot food safer and more convenient. This feature directly aligns with the findings from the hypothesis testing, which confirmed that PGD positively influences CUI by improving consumer perceptions of safety and usability.

Figure 3 Double-handle design

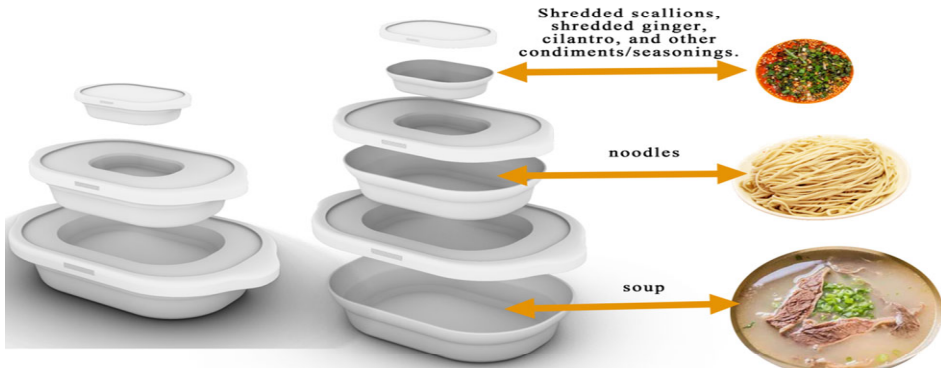


Figure 4 A movable divider design (see online version for colours)



CD The adjustable CD allows users to customise the container for different meal types, enhancing its flexibility and functionality. By incorporating detachable compartments, the design allows for easy cleaning, addressing consumers' concerns about hygiene (Figure 4). CD was shown to have a significant positive effect on CUI, particularly for individuals who prioritise convenience in food packaging. This modularity also contributes to the sustainability of the product, as it enables better portion control and reduces food waste.

Figure 5 The modular design of the container (see online version for colours)



The MD of the container, as exemplified by the beef noodle container (Figure 5), the container features a layered structure: the bottom layer holds the soup, the middle layer separates the noodles to keep them dry, and the top layer stores seasonings to maintain freshness. The heat from the soup naturally circulates to the noodles, keeping them at an ideal temperature. This design balances taste, texture, and temperature, enhancing the dining experience. The study found that MD significantly improved CUI by increasing convenience, ease of use, and customisation options. Consumers can quickly assemble or disassemble the container for daily use, cleaning, or storage. Moreover, the modular structure allows consumers to choose the number and type of compartments based on their preferences, catering to individual needs. The MD showcases the potential for innovative food packaging solutions in the takeaway industry. By improving functionality, convenience, and customisation, this design leads to higher CUI and serves as a model for future container designs.

4.6.2 *Design features and functionality*

Our design framework synthesises multiple innovative elements to advance functionality, enhance user experience, and promote environmental sustainability. The integrated features represent a thoughtful response to both practical needs and ecological concerns:

The ergonomically engineered heat-resistant grip exemplifies our focus on user safety and comfort, incorporating a robust handle system that ensures secure handling of heated contents. This design element particularly addresses the critical need for safe food transport and handling in daily use scenarios. Our adaptive compartment system introduces a flexible space management solution, allowing users to customise storage configurations based on diverse food storage requirements. This versatility directly responds to varying user needs across different meal types and portion sizes. The

innovative detachable component architecture facilitates thorough cleaning and maintenance, significantly enhancing hygiene standards and user satisfaction. Each component has been engineered for easy disassembly while maintaining structural integrity.

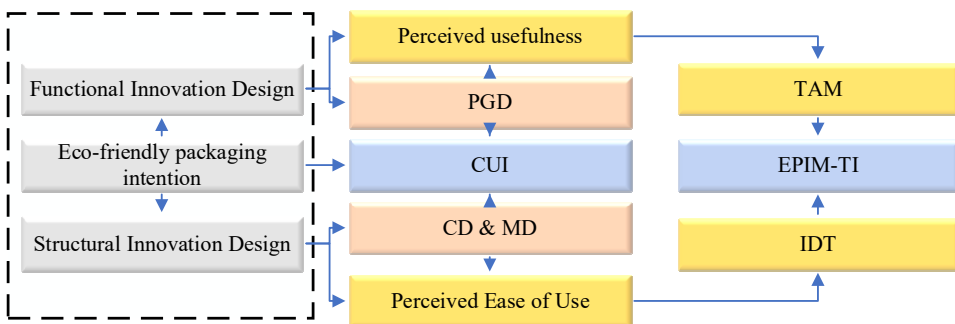
At the core of our design lies the strategic utilisation of sugarcane bagasse, chosen for its exceptional combination of biodegradability, structural strength, and compostability. This material choice directly addresses growing environmental concerns while meeting rigorous performance requirements. The intelligent stackable architecture optimises storage efficiency through a space-conscious design that maintains full functionality while minimising storage footprint during periods of non-use.

4.7 EPIM-TI

Based on the results of Smart-PLS analysis, EPIM-TI fully reveals the key driving factor to accept environmentally friendly packaging (Figure 6). The study integrates the core theories of TAM and IDT, and verifies the multiple influencing paths of PU, PEOU, FID and SID on CUI. The analysis shows that PU and FID are significant direct influencing factors with the highest path coefficients. When sustainable environmentally friendly packaging has substantial value in actual use, its willingness to accept is greatly improved. At the same time, PEOU indirectly enhances PU by enhancing SID, further enhancing environmental attitudes.

The core findings of the EPIM-TI model demonstrate the transformative potential of technological innovation in environmentally friendly packaging design. Consumer behaviour data show that SID has the most significant impact on promoting the acceptance of environmentally friendly packaging, demonstrating the great potential of material intelligence and MD. At the same time, FID has become an important link in driving consumer behaviour by improving user experience. Statistical results show that consumers' average recognition of CD is 3.897, followed by MD at 3.804, reflecting the superiority of SID. Through path analysis, the model verifies the strong correlation between technological innovation and consumer intention, and clarifies the strategic orientation of innovative design. EPIM-TI not only sets a benchmark for technological innovation in the environmentally friendly packaging industry, but also provides a new solution for achieving a win-win situation for ecology and economy.

Figure 6 Eco-friendly packaging intention model based on tam and IDT (see online version for colours)



4.8 Discussion

This study investigates how functional and structural design innovations affect consumer adoption of environmentally friendly bagasse food containers. The results show that PGD significantly enhances CIU by improving usability and safety. This design not only facilitates consumers to lift and carry the container during use, but also enhances the safety of the container, making it more stable during use and avoiding the risk of tilting or tipping over. On the other hand, CD and MD attract consumers by providing customisation and hygiene advantages. The CD can meet consumers' needs for separate storage of different foods and reduce cross-contamination between foods, while the MD provides more personalised options through detachable and adjustable components, allowing consumers to flexibly adjust the structure of the container according to their needs. The synergistic effect of these innovative designs creates a more comprehensive product supply that meets the diverse needs of consumers, while also promoting the goal of sustainable development.

From a theoretical perspective, this study makes an important contribution to the expansion of TAM and IDT. We verify the key role of functional and structural design innovations in consumer adoption behaviour, especially when these innovative elements can effectively improve the practicality, safety and customisation of the product, consumers' acceptance intention will be significantly improved. By combining functional innovations that enhance safety and convenience with structural innovations that promote flexibility, manufacturers can not only meet consumer demand for sustainable products, but also promote the popularity of green packaging in the market. The MD approach meets the needs of different consumers by providing adjustable compartments and interchangeable parts while ensuring the sustainability of the product. This design approach enables the product to meet the concept of environmental protection and energy saving while meeting the needs of daily use, further promoting the realisation of sustainable development goals. Therefore, the results of this study have important practical guidance for manufacturers, that is, to focus on the integration of user-friendliness, convenience, safety and customised functions in the design process to enhance the market competitiveness of products.

However, although this study provides valuable insights, it also has certain limitations. First, the sample size of the study is small ($n = 179$) and the cross-sectional research design is adopted, which limits the generalisability of the research results. Future research can consider expanding the sample size and covering consumers from different regions and cultural backgrounds to more fully understand the influence of functional and SIDs on a global scale. In addition, a longitudinal research design will help reveal the trend of consumer behaviour changes over time, thereby better predicting long-term product acceptance and market response. Secondly, this study focused on the functional and structural innovative design of the product, but factors such as aesthetic design, pricing strategy, and brand influence also play an important role in consumer decision-making. Therefore, future research can further explore the impact of these factors on consumer adoption intention to improve the overall design framework. Finally, the comprehensive assessment of the environmental sustainability of bagasse materials during the life cycle remains an area worthy of in-depth research. Although this study focused on the potential of bagasse as a sustainable material, a systematic LCA of the environmental impact of its production, use, and recycling will help provide consumers and manufacturers with a more scientific and comprehensive decision-making basis. In

summary, this study provides valuable theoretical support and practical guidance for the sustainable packaging industry. By systematically analysing the impact of functional and structural innovative design on consumer adoption intention, we proposed a comprehensive design framework (EPIM-TI) to help manufacturers better meet the growing needs of consumers while promoting the popularity of environmentally friendly food containers. Future research can further explore a wider range of influencing factors, such as market positioning, cultural differences, and full LCA, to promote the development of the sustainable packaging field and promote the practical application of green innovation.

5 Conclusions

5.1 Unique contribution

This research provides a novel contribution to the understanding of consumer acceptance of environmentally friendly packaging by investigating the impact of functional and structural innovations in bagasse food containers. Through integrating the IDT and the TAM, the study introduces the EPIM-TI framework, which reveals how the synergy between functional and structural designs enhances consumer willingness to use eco-friendly products. The findings highlight that consumers' acceptance is not solely dependent on the environmental benefits of packaging but also on its functionality, convenience, and the personalisation options it offers. The paper thus expands the theoretical scope of sustainable packaging by combining key design factors and adoption models, offering valuable insights into how innovation influences market acceptance.

5.2 Limitations of the study

While the study provides important insights, it also has several limitations. Firstly, the sample size ($n = 179$) was relatively small, and the study was geographically restricted, limiting the generalisability of the findings to broader populations. Additionally, this research focused primarily on functional and structural design innovations, excluding other potentially significant factors such as aesthetic design, price sensitivity, and brand influence, which could also affect consumer behaviour. Furthermore, this study did not address the environmental impact of the bagasse materials themselves, such as through a life cycle assessment (LCA). The limited scope of environmental evaluation may hinder a complete understanding of the ecological advantages and disadvantages of using bagasse in packaging.

5.3 Future research directions

Future research can build upon the findings of this study by expanding the sample size and incorporating a more diverse range of consumers from different cultural backgrounds and geographical locations to validate the results on a broader scale. It would also be beneficial to investigate additional factors that may influence consumer acceptance, including the role of aesthetic design, pricing strategies, and the influence of brand reputation. Another key area for future research would be the application of LCA to evaluate the full environmental impact of bagasse-based packaging, providing a more

comprehensive view of its sustainability. Understanding the trade-offs involved in using bagasse materials for packaging could further strengthen the argument for environmentally friendly packaging solutions and guide the future development of sustainable products in the packaging industry. Additionally, exploring the interaction between innovation in functional and structural design and other consumer behaviours, such as environmental attitudes and ethical consumption, could provide further insights into how to optimise the design and marketing of eco-friendly products.

Disclaimer

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