sustainability

MDPI

Article

Assessing the Feasibility of Practical Cradle to Cradle in Sustainable Conceptual Product Design

Xiaochen Zhang [1,2], Xinyu Liu [1], Yang Zhang [1], Xing Xu [1], Jiaxin Xiao [1] and Ding-Bang Luh [1,2,*]

1 Department of Industrial Design, Guangdong University of Technology, Guangzhou 510090, China; xzhang@gdut.edu.cn (X.Z.)
2 Guangdong International Center of Advanced Design, Guangdong University of Technology, Guangzhou 510090, China
* Correspondence: luhdingbang@gdut.edu.cn

Abstract: This paper delves into the feasibility of implementing Cradle to Cradle (C2C) principles in conceptual product design to achieve sustainability objectives. By developing two concept products and conducting a series of qualitative and quantitative experiments, this research demonstrates the potential of the C2C approach as a crucial guide in the design process and emphasizes its significance in creating environmentally and socially responsible products. Nevertheless, this study also highlights the challenges and limitations associated with the practical application of C2C theory and the attainment of optimal product performance. These findings underline the importance of integrating C2C principles into conceptual product design and call for further research to address the limitations of the theory and optimize its application in sustainable design. Overall, this research contributes to the growing body of literature on sustainable design and provides valuable insights into the potential benefits and challenges of adopting the C2C approach in conceptual product design.

Keywords: Cradle to Cradle (C2C); conceptual product design; sustainable design

Citation: Zhang, X.; Liu, X.; Zhang, Y.; Xu, X.; Xiao, J.; Luh, D-B. Assessing the Feasibility of Practical Cradle to Cradle in Sustainable Conceptual Product Design. *Sustainability* **2023**, *15*, 6755. https://doi.org/10.3390/su15086755

Academic Editors: Santosh Jagtap, Lucia Corsini and Ting Chi

Received: 13 March 2023
Revised: 7 April 2023
Accepted: 13 April 2023
Published: 17 April 2023

1. Introduction

The world's growing population and increasing demand for goods and services have led to a surge in the consumption of resources. It is projected that by 2030, over 3 billion people will have entered the middle class, resulting in an unprecedented demand for goods and services [1]. This projection has put pressure on achieving sustainable development goals, leading to a growing interest in sustainable product design and development in recent studies [2]. Environmental pollution is a major issue with catastrophic effects on the world [3], and one of its causes is the negative impact of raw material consumption on the environment, including atmospheric pollution, emissions to the natural environment, and harmful effects on biodiversity [4]. Therefore, designers and manufacturers have a critical role to play in reducing the total consumption of a product throughout its life cycle, especially during the early stages of product development [1].

Product development involves four general phases, including the "specification" phase, "conceptual design" phase, "detail design" phase, and "manufacturing" phase. The design phase has a significant impact on the environmental footprint of products, with 70–80% of a product's environmental impact being determined at this stage [5]. Moreover, 60% of product life cycle costs are determined during the conceptual design stage [6]. Therefore, it is crucial to consider sustainability aspects during product conceptual design [7]. Conceptual design is primarily a design process that involves defining the task, formulating the functions and structures of the product, seeking the most applicable combinations and principles, and identifying basic solution paths [8]. Sustainability assessment during conceptual design can identify products with minimal environmental impact while ensuring the social and economic aspects of the product [2]. Therefore, research should be conducted during the first and second stages of the product development process to achieve maximum benefits.

In 2002, the book *Cradle to Cradle: Remaking the Way We Make Things* was published [9]. The Cradle to Cradle philosophy aims to shift our focus from "doing less harm" to "doing better" [10]. While the traditional eco-efficiency approach focuses on minimizing our ecological footprint and reducing damage to the environment, Cradle to Cradle prioritizes eco-effectiveness by encouraging positive impact. Recently, various theories and methods have been developed to evaluate product environmental performance in different levels of detail [11], including carbon [12] and water foot printing [13], Life Cycle Assessment (LCA) [14], and the European Commission (EC) Product Environmental Footprint (PEF) methodology [15,16]. However, these approaches have their own definitions of sustainable products and concentrate on manufactured products, with less attention given to conceptual design. In contrast, Cradle to Cradle design approaches such as the Cradle to Cradle Certified™ Product Program [17] have not undergone sufficient scientific testing, hence the need to study Cradle to Cradle design in the conceptual design phase to fill the gap in product development processes. Although the existing literature provides some insight into the strengths and weaknesses of C2C, its scope is limited (e.g., Bakker et al. analyze the C2C principle's applicability to student design projects) [18]. Therefore, there is a need for comprehensive and reliable scientific analysis of C2C in the product conceptual design phase.

This paper aims to assess the feasibility and validity of applying Cradle to Cradle theory to product concept design through qualitative and quantitative experiments. By doing so, we propose a design method based on Cradle to Cradle theory in the product concept design phase. The feasibility of this method is verified by analyzing the choice of product concept design methods and the feasibility of concept design products based on Cradle to Cradle theory.

As depicted in Figure 1, we also regard both the C2C theory and product concept design as integral components of sustainable design. The combination of these two elements offers a novel interpretation of sustainable design theory within the context of academic research.

The previous literature has established the connection between Cradle to Cradle theory and packaging development approaches [10], demonstrating the potential for integrating Cradle to Cradle theory with other product development theories. To test the feasibility of Cradle to Cradle theory in product concept design, we propose a methodology that combines qualitative and quantitative experiments to analyze the relationship between data and concepts [19]. The research method is assessed by applying it to different product concept scenarios and comparing experimental data. The results of this study provide validation for the proposed method.

The remainder of this paper is structured as follows. The second section presents related research work. The third section outlines the research methodology and experimental design. The fourth section validates the proposed method and compares it to other experimental subjects using maize seeds as an example. Finally, the fifth section concludes this paper and suggests future research directions.

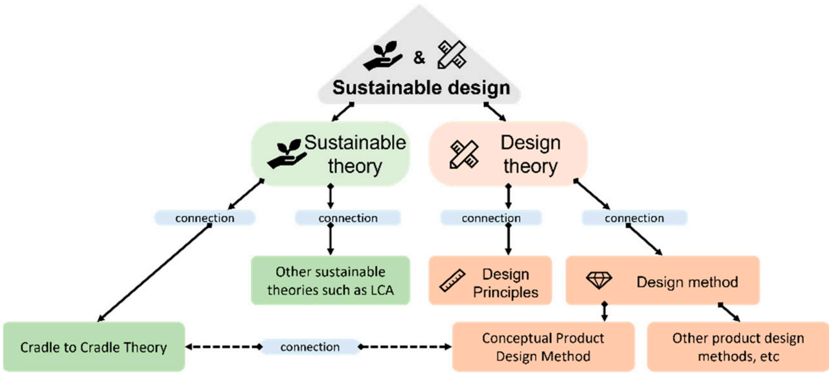

Figure 1. This article distinguishes between two distinct areas of sustainable design research, namely, sustainability theory and design theory. Sustainability theory encompasses concepts such as LCA, C2C, and PEF, while design theory focuses on the principles and methods of design. In this article, we aim to integrate C2C theory from sustainability theory with the conceptual design method from design theory. This integration can enhance our understanding of sustainable design and provide practical solutions for creating environmentally friendly products.

2. Theoretical Background

In this section, we provide a comprehensive overview of the current research on product concept design methods and the state of Cradle to Cradle theory and design methods. We present a detailed analysis of the existing literature on the topic, highlighting the strengths and limitations of current approaches, and identifying research gaps that need to be addressed.

2.1. Conceptual Design and Evaluation

In a 2015 article, the authors conducted a comprehensive review of 273 articles addressing product design definitions, with a particular focus on extracting several aspects from 43 articles that are pertinent to conceptual product design. These aspects encompass (1) aesthetics, (2) functionality, (3) symbolism, (4) form, (5) ergonomics, and (6) other factors [20]. This demonstrates that the pursuit of innovation across various dimensions has consistently been a focal point within the product design research field. Product novelty has long been acknowledged as a key factor in new product development (NPD) [21], with researchers increasingly concentrating on the conceptualization and measurement of innovation in recent years [20]. Conceptualization encompasses both the theoretical significance of product design in terms of definition and the early stages of product development, such as the testing of prototypes or product concepts, which hold considerable value [20].

In previous research, product concept design approaches incorporating aesthetic, functional, and symbolic elements have been proposed [22]. Although the methodologies employed in various studies differ substantially, the majority of authors concur that product innovation represents a multi-dimensional concept. Consequently, most new products undergo proof of concept and prototype testing and evaluation before being launched into the market [23].

Concept design evaluation is a critical aspect of the product development process, as it directly affects the quality, cost, and desirability of the final product [24,25]. However, concept evaluation is a complex, multi-objective decision problem, as the objectives of two subjects, technical and economic characteristics of the product, are in natural competition. One of the major challenges in concept selection is to find a solution that obtains the maximum combined value under conflicting objectives [26,27].

Various approaches to conceptual design evaluation exist, including solution evaluation techniques that combine customer needs and designer limitations proposed by Tiwari et al. [28], visual analysis methods based on the Kano model suggested by Atlason et al. [29], and a focus on demand from different stakeholders in the innovation diffusion process proposed by Cantamessa et al. [30]. Although numerous research approaches and theories in conceptual design methods exist, some are better justified by data or quantifiable research methods such as parameters. For instance, the PDS-behavior-structure conceptual design model proposed in 2016 [31] is a data-supported method that helps determine reasonable conceptual design solutions for multi-disciplinary-oriented complex product systems. The evolutionary game-based product concept design approach proposed in 2019 [32] discusses how the concept in the product development cycle decisively affects cost and performance. In the same year, binary semantics was proposed [33], with a case study used to illustrate the method. Considering the role of information ambiguity in product concept design, an intuition-based fuzzy group decision product concept design method was suggested. In 2019 [34], a CBDT-TRIZ model was established to help design engineers make informed decisions quickly, thus speeding up the design process. Another conceptual design approach based on conceptual knowledge modeling and eye-tracking data analysis was proposed in 2019 [35] to analyze the factors influencing the individual-level transfer of engineering knowledge. In 2020, the use of group decision making and intuitive fuzzy preference relationships was proposed to quantify conceptual schemes that consider sustainability attributes [36]. However, building validation models quickly and using strategies such as group decision making is not an easy challenge and has the potential to increase design costs. For example, in 2012, the authors of [37] discussed how using the wrong representation at the wrong stage of design development can lead to inefficiencies and costly redesigns.

In contrast, simple and general analytical methods that are used in all fields, such as quantitative and qualitative studies, offer great advantages. In recent decades, these research methods have been applied to studies in the fields of psychology [38], medicine [39], and education [40], respectively. In a 2016 article [41], quantitative research was seen as providing “hard”, “factual” data, while qualitative research was described as softer, providing more in-depth insight. Although quantitative and qualitative research methods are widely used in various fields, little is known about the feasibility of discussing C2C theory in the context of conceptual product design. As products and product services become increasingly complex [42], co-innovation and competitive design-driven innovation [43] will be pursued through multi-disciplinary collaborations.

2.2. Cradle to Cradle (C2C)

The publication of the book *Cradle to Cradle: Remaking the Way We Make Things* [9] marked a significant shift in the theoretical study of eco-efficiency. Cradle to Cradle (C2C) theory [9] proposed in 2005, consisting of three principles—waste as nutrient, use of renewable energy, and promotion of diversity [44]—is essential in defining eco-efficiency and life cycle. The research based on C2C theory extends to various products and systems, including the conversion of materials into nutrients proposed through biometabolism and technometabolism in 2007 [45], recycling production methods developed in 2019 [46], and the assessment of the environmental potential of urban pavements in 2021 [47]. However, the effectiveness of C2C-guided formation in the conceptual design section, which is often skipped in most studies, should also be studied.

C2C theory is currently mainly applied in the field of strategy analysis and circular economy. For instance, a circular economy and C2C were used for university teaching in 2018 [48], environmental adaptation strategies based on ecological goals were proposed in 2019 [49], and a literature review on the application of a circular approach to education for sustainable development was conducted in the same year [50]. Moreover, Cradle to Cradle production solutions were proposed for used furniture in 2020 [51], while C2C was proposed as a product design concept rooted in “healthy” material circulation to address the disadvantages of a circular economy in 2021 [52]. Although there are few methods to directly evaluate the feasibility of C2C theory, it is often used as a guide to analyze cases.

The current study explores the connection between C2C theory and product conceptual design. In 2010, it was noted that the C2C approach can serve as a complementary method in the design process and offer guidance for conceptual product development. However, it is prone to dogmatic errors, making it unsuitable for all product designs [53]. In contrast, utilizing experimental and numerical analysis to establish a proof-based conceptual product design process guided by the conceptual design approach ensures the scientific rationality of solution formation and output. This approach helps to enhance the efficiency and quality of product design [54].

According to a 2019 study [55], the new knowledge society will undergo changes along with new cognitive differences. Exploring product conceptual design before implementing a landing solution will be an opportunity for future innovation. This study aims to address this issue by verifying the value and feasibility of C2C theory in concept design before product landing, using various research methods such as qualitative and quantitative. It is also proposed, as in 2019 [35], that the rational reuse of past experiences can facilitate product innovation. Moreover, a 2020 study [56] suggests that the importance of cross-domain knowledge for product innovation design is continuously increasing, including the reorganization, transfer, and transformation of multi-domain knowledge. Emphasizing the conceptual design phase of research can also promote innovation.

3. Methodological Approach

In this section, we propose an evaluation scheme based on qualitative and quantitative experiments to determine whether Cradle to Cradle (C2C) theory can guide the design of a good concept product, and we present the limitations of the method. The feasibility of C2C theory in product concept design is evaluated through a data analysis-based product concept design approach combined with relevant quantitative and qualitative experiments, with the experimental analysis-based scheme applied to determine the feasibility of the theory more comprehensively in multiple directions.

The framework diagram of this study, shown in Figure 2, is based on a combination of qualitative and quantitative analysis methods, a product concept design approach based on data analysis, and the principles of waste and nutrients in C2C theory. To avoid the subjective, relative understanding that occurs in qualitative-based analysis, especially for qualitative methods that assume only partially objective descriptions of the world that can be understood in various ways [19], we use data analysis such as numerical modeling, which is more likely to receive the influence of experimental data and rigor of experimental settings. Finally, we combine these two approaches to create an effective and flexible research methodology, which provides more knowledge and insight into the research topic [57].

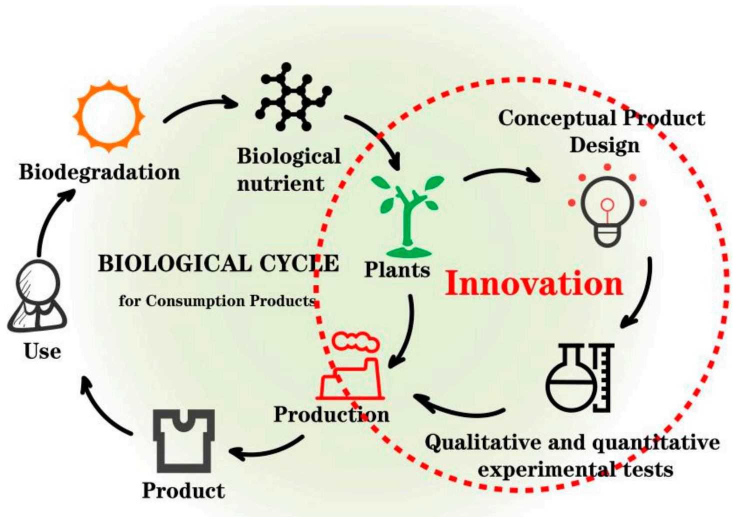

Figure 2. This paper employs a combined qualitative and quantitative experimental approach to validate the feasibility of integrating C2C theory with conceptual product design. The qualitative

and quantitative experiments provide valuable data support for the theory, while the theory provides a logical framework for the experiments. What sets this study apart is the approach taken, which begins with the key principles of C2C theory and combines them with conceptual product design methods to discuss the feasibility of the theory using a qualitative and quantitative experimental validation method.

Our current research aims to further understand the testing and corroboration of C2C theory by qualitative and quantitative experiments during conceptual product design. Therefore, we will attempt to better explain the importance of C2C theory for the product conceptual design phase. Here, we explain the validity of the guidance of C2C theory for concept product design from experiments such as qualitative and quantitative. The overall sense of effectiveness depends on the value of the number of experiments and the different types of experimental approaches. However, the current study explores the implications of C2C theory in the product concept design phase.

From this perspective, we hypothesize that if the setup of qualitative and quantitative experiments is influenced by the norms, rules, and conventions of different fields for experiments, then the presentation of the experimental results differs depending on the field of expertise. In this regard, we expect designers to pay more attention to the rationality of the experimental approach argumentation and the impact on theoretical innovation. In contrast, research by means of data analysis, such as building numerical models, is more likely to receive the influence of experimental data and the rigor of experimental settings. On the other hand, innovation in theory is likewise based on different understandings of multiple identical knowledge, which is in line with [35], who suggested that the rational reuse of past experience can facilitate design innovation, i.e., innovation is about the scientific yet logical use of existing knowledge.

A practical and strategic expression of the eco-efficiency concept of "Cradle to Cradle" defines a framework for designing products and industrial processes so that living systems can be used for human purposes and safely returned to the environment for use in biological processes that do not cause immediate or ultimate harm [9]. To achieve these goals, we designed two conceptual products (hollow maize seeds and absorbing ball) using C2C principles and examined their responses in quantitative and qualitative experiments.

3.1. Design of Conceptual Products

In this section, we will discuss how the theory of C2C, which envisions a future of environmental sustainability, has been incorporated into the design of our concept product [58]. A 2017 article published in Springer Press's Life Cycle Assessment issue elucidated that the objective of C2C is to exert a positive influence on the environment, encompassing human well-being [59]. To attain this goal, three fundamental design principles ought to be adhered to throughout the process: waste as a resource, utilization of current solar income (renewable energy), and the celebration of diversity [17,59]. Consequently, our design also follows these three key principles:

1. The principle of waste equals food, which requires that all materials and emissions be considered beneficial to the environment or the technosphere. Our product has been designed to be harmless to human health and sustainably recyclable, with no waste generated and all outputs serving as inputs to other systems. This allows us to establish closed-loop systems based on these cycles.
2. The principle of enhancing renewable energy sources, which we consider essential to effective design. We have maximized the use of renewable energy sources wherever possible.
3. The principle of focusing on diversity, which is a key to innovation in designing technologically diverse products that avoid a "one-size-fits-all" approach.

Our concept product is designed to absorb food, with potential uses including obstructing food absorption and aiding in weight loss [60]. The increasing rate of obesity is a global public health problem, particularly among girls who are struggling to achieve a socially acceptable ideal body [61,62]. Long-term or chronic attempts to lose weight can have serious consequences on the physical and mental development of young people, with female dieters being more likely to suffer from nutritional deficiencies, growth retardation, menstrual irregularities, delayed sexual maturation, irritability, sleep disturbances, and poor concentration [62,63]. A three-year follow-up study conducted in the United States [64] showed the most commonly employed methods for weight loss among adults were exercise and maintaining healthy eating habits.

Our concept product is designed to allow normal eating behavior without the need for dieting. Rather than eating less food, our product absorbs the "extra" food, which is expelled from the body during the digestion process. This approach helps users solve the problem of eating less food and dieting, making our product more appealing to users.

Figure 3 elucidates how the conceptual product is utilized by users and delineates its role in each stage of human digestion. Meanwhile, Figure 4 exhibits the packaging and product rendering of the conceptual product under examination.

In the following sections, we will discuss the research that has been conducted in three areas: material selection, structural design, and derivative concept products of our design, all of which are in line with the principles of C2C.

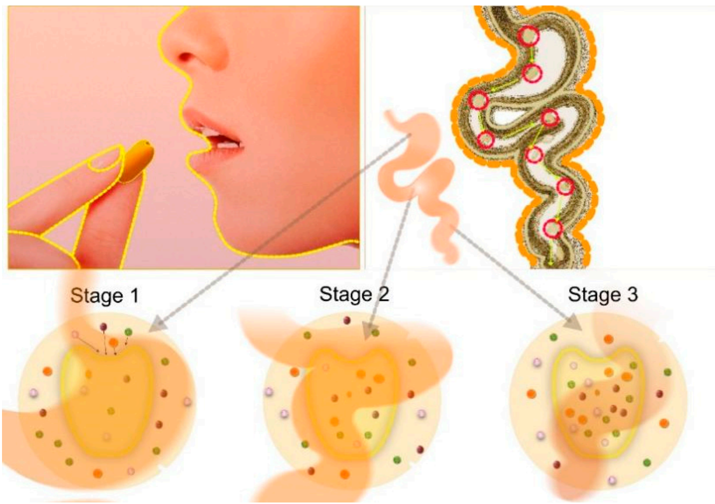

Figure 3. The product undergoes ingestion and enters the human digestive system. During the first stage, the product and food pass through the stomach, where the vigorous movements break food down into smaller particles. Subsequently, the product gradually absorbs some of the food. In the second stage, the product traverses the small intestine, where the food undergoes further degradation due to the coordinated movements of the small intestine. The external cellulose of the product serves to prevent the villi of the small intestine from coming into contact with other digestive fluids and food that may be absorbed by the product, while allowing the product to absorb more food. Finally, the product enters the large intestine during the third stage, where peristalsis expels it from the body along with the absorbed food. Therefore, the workflow of the product obviates the need for users to restrict their diets to achieve a reduction in food absorption.

Figure 4. The above figure illustrates the structural blueprint of a conceptual product. The upper part of the product features an angled aperture, which facilitates food intake, while the lower end

has multiple small orifices to discharge digestive enzymes. Upon entry of food into the product, the downward sloping aperture creates a unidirectional pathway, making it difficult for the food to escape. Consequently, a state of ease in food ingestion but difficulty in excretion ensues. The bottle product, in turn, is a consequence of the packaging design.

3.1.1. The Application of Cradle to Cradle (C2C) Theory in Material Selection for Concept Products

According to the principles of Cradle to Cradle (C2C) theory, products should be designed in a way that they can be recycled sustainably and be health-friendly to humans [65,66]. Sustainable design using raw materials from nature is exemplified in Indonesia, where designers have utilized pineapple leaf fiber as a fashion material [67]. Similarly, the concept product design discussed here utilizes maize seeds, a common plant from nature.

Maize (*Zea mays*), also known as the queen of grains, is a miracle crop and the third-most important cereal crop in the world after rice and wheat [68]. The pericarp of each maize kernel, which makes up approximately 7% of its weight, contains fiber cells rich in phytochemicals [58]. The cellulose in the pericarp protects the kernel from being digested by the body, making it a natural design material without damaging the epidermis.

The selected material for the concept product design is maize seeds, which takes advantage of the fact that maize is not easily digested by the human body. Additionally, the starch in sun-dried maize undergoes hydrolysis during storage, resulting in a hollowed-out internal starch in maize seeds that contains very little starch. This provides a solid research basis for experimental validation of the concept product [69].

The flow of maize seeds in nature is similar to the flow of biotrophs, or substances that optimally flow in the biological metabolism of organisms [45]. Biotrophs can include natural or plant-based materials, as well as biopolymers and other potentially synthetic substances that are safe for human and natural systems. Biological metabolism encompasses resource extraction, manufacturing and client use, and the eventual return of these materials to natural systems, where they can be transformed into resources for human activities [45]. Therefore, the selection of maize seeds aligns with C2C theory's principles of enhancing renewable energy.

3.1.2. Guiding Conceptual Product Structure Design with Cradle to Cradle (C2C) Theory

The proposed concept product is primarily designed to absorb food efficiently while preserving the material's integrity. Therefore, it is critical to devise a structural design that enhances food absorption while inhibiting its efflux.

To address this challenge, we propose a novel design that features a downward sloping opening at the top of the product. As food enters through the opening, it becomes ensnared by the sloping surface, preventing any attempts to escape. The product structure's bottom is hollow and includes several small openings to drain water from the absorbed food, while minimizing the presence of digestive juices or other liquids. Figure 5 presents the two conceptual product prototypes designed by our research team.

Our design is carefully crafted to improve food absorption while maintaining the material's integrity, in line with the principles of "Cradle to Cradle" theory. By minimizing waste and maximizing resources, our concept product offers a sustainable and efficient solution for food absorption.

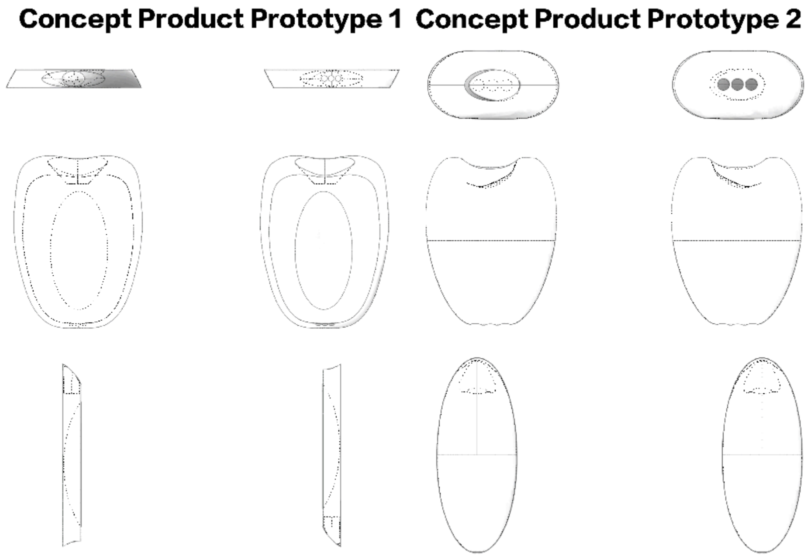

Figure 5. Six views of two conceptual product prototypes based on maize seeds are displayed. These designs aim to retain the natural product's appearance, potentially enhancing user acceptance psychologically.

3.1.3. Designing Concept Product Derivatives through Cradle to Cradle (C2C) Theory

Following the fundamental principles of C2C theory that emphasize the recognition and appreciation of diversity, we developed a conceptual design based on maize seeds along with a unique derivative featuring an angled opening at the top. Figure 6 depicts the derivatives of the four conceptual products designed by our research team.This was performed to ensure consistency in the primary functions of the experiment. The main objective of the experiment was to evaluate the uptake capacity of the maize seed-based derivative and compare it with that of the maize seeds. Additionally, we aimed to determine whether the derivative could outperform maize seeds in terms of uptake quantity. Figure 7 presents the optimal product selected from the derivatives of the four conceptual products after conducting a comprehensive multi-dimensional evaluation.

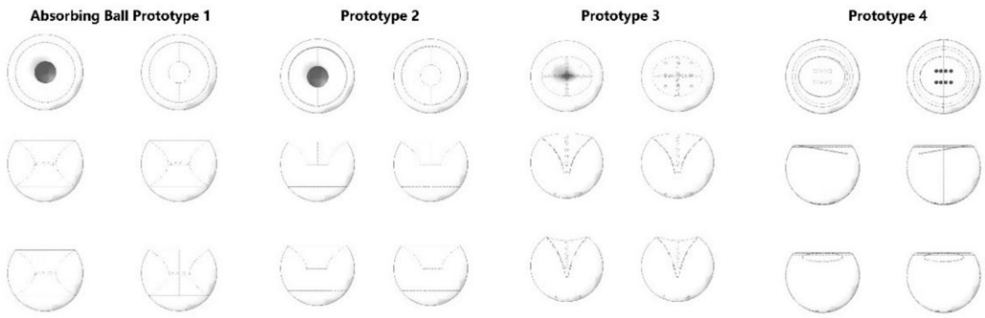

Figure 6. In accordance with the C2C principle of valuing diversity, the design of the derivative ball departs from the original concept product. As a product with conceptual diversity, the purpose of the derivative ball is to maintain the functionality of the concept product while enhancing its performance. To that end, four derivative ball were designed, with each following the principles of C2C theory.

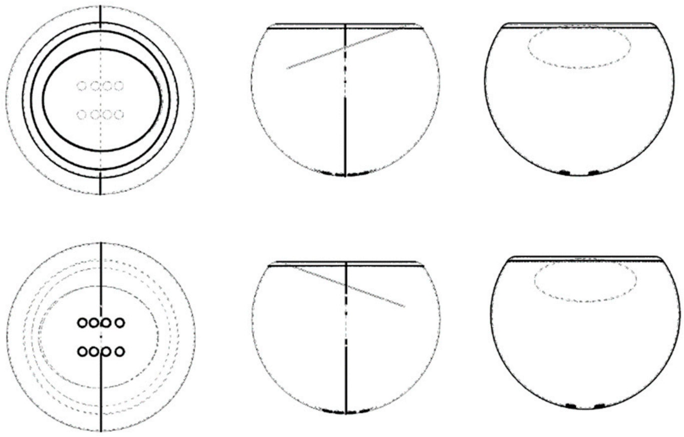

Figure 7. After careful evaluation of four derivative ball designs, we chose the final experimental prototype. Our evaluation was based on the complexity of the 3D printing process and the internal space of each prototype. Ultimately, we determined that Prototype 4 was the optimal choice.

3.2. The Purpose and Methodology of Experimentation on Concept Products and Derivatives

The methods of material preparation, direct seed experiments, transplantation experiments, and statistical analysis mentioned in 2006 [70] are primarily used in horticultural science research. Given that this study involves the selection of natural crops and similar data analysis, traditional research methods [31] such as the proposed conceptual design model to support product design are not applicable. Instead, the chosen research method involves experimental and data analysis. Furthermore, this approach emphasizes the influence of the conceptual model on the product design. In contrast, direct seed and transplantation experiments provide better analytical ideas for iterative product design. The experiment was mainly conducted indoors, and its purpose was to verify whether the conceptual product, hollow maize seeds designed using C2C theory, and its derivative product, absorbing ball, could absorb different types of foods.

One of the challenges addressed during this study was how to confirm the validity of the combination of the two theories through data argumentation. One way to overcome this issue is the proposed process of applying theory and experiment to conceptual design in [71,72]. Additionally, in 2019 [34], a method for justifying the rationality of the combination was proposed.

Furthermore, the research process is crucial for selecting conceptual design solutions, and in 2019 [73], a decision-making method was proposed to evaluate the relative equilibrium of conceptual designs. This method addresses the problem of option selection in conceptual design. However, the current study primarily focuses on the analysis of experiments and data, rendering this method irrelevant. Nevertheless, solution selection remains a crucial component in conceptual design.

This paper employs two methods to quantify the combinability between the two theories. Firstly, direct seed experiments are combined with quantitative and qualitative experiments [74] in horticultural science research [70] to demonstrate the feasibility of selecting materials for the conceptual product. Secondly, the rationality of the concept product is argued through transplantation experiments and derivative experiments. Additionally, since there are ethical issues regarding the validation of the concept product through human experiments, this paper uses the above two methods to bypass human experimentation and validate the study's content.

3.3. Design of Quantitative and Qualitative Experiments

In general, quantitative studies involve predetermined data collection and require the researcher to carefully describe variables that can be computed numerically. This approach is often viewed as reductionist, where the truth is reduced to a number [19], and assumes that variables can be measured objectively. In this approach, the study of cause-and-effect relationships between or among variables is typically of interest [19]

To set up a quantitative experiment for hollow maize seeds, three small groups of experiments were established. On the other hand, qualitative studies have flexible designs and measurement of variables that depend on the context of data collection. Qualitative methods assume that only partially objective descriptions of the world can be produced and thus can be understood in various ways [19]. Therefore, to enrich the variety of experiments, the qualitative experiments were divided into two groups, which contained six small groups of experiments.

Additionally, a qualitative experiment group was established for the derivative absorbing ball, which included two small groups of experiments. Figure 8 illustrates the design of both quantitative and qualitative experiments.

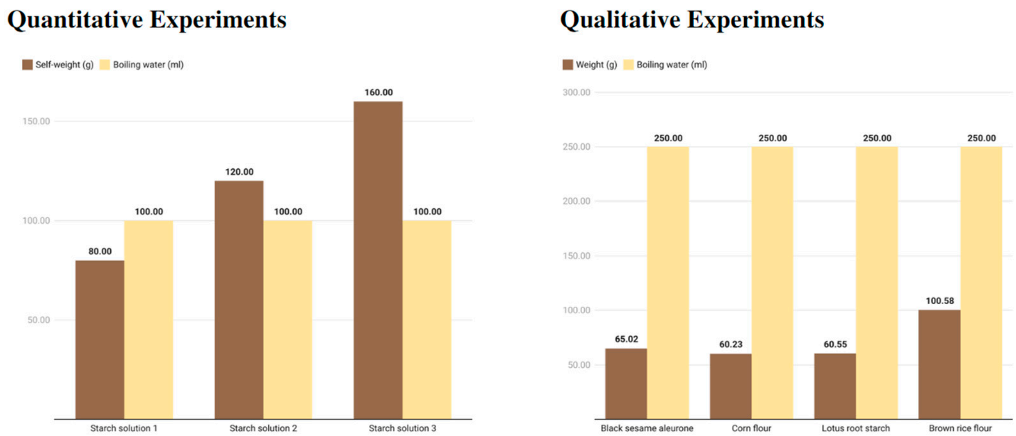

Figure 8. The design of qualitative experiments for the concept product involved four different solutions: black sesame pastes, maize paste, lotus root powder, and brown rice flour. Furthermore, the design of quantitative experiments for the concept product involved three different concentrations of starch solutions.

3.3.1. Preparation of Experimental Materials

Prior to conducting the experiments, the materials for both the quantitative and qualitative studies were carefully selected and prepared. For the quantitative experiments, starch was used as the experimental material. For the qualitative experiments, four different materials were selected, namely, lotus root powder, maize paste powder, black sesame paste powder, and brown rice powder.

Furthermore, several essential tools and equipment were prepared, including plastic bottles for rotation, a motor, an electronic scale, a measuring cup, a rotating fixed structure, a rotating track, an adjustable power supply, tweezers, and a number of hollow dried maize. This ensured that the experiments were conducted accurately and effectively.

3.3.2. Experimental Introduction—Experiments on Hollow Maize Seeds Using Quantitative and Qualitative Methods

- Quantitative Analysis Experiment—Starch Solution Experiment

The purpose of this quantitative analysis experiment was to investigate the ability of hollow maize seeds to absorb different concentrations of solutions prepared from the same material. Three experimental groups were established, with concentrations of 80 g/100 mL, 120 g/100 mL, and 160 g/100 mL. The experimental solutions were created by mixing starch with water at room temperature. The independent variable was the experimental time, with intervals of 5 min, 10 min, 15 min, 20 min, and 25 min. The dependent variable was the weight of hollow maize seeds after absorbing the solution. The experimental subject was hollow maize seeds, with a total of eight seeds used in the experiment.

- Qualitative Analysis Experiment—Multiple Solution Experiment

In this experiment, the purpose was to verify whether hollow maize seeds have the ability to absorb solutions of similar concentrations prepared from different materials. Four groups were created with different ingredients: black sesame paste powder (65.02 g/250 mL), maize paste powder (60.23 g/250 mL), lotus root powder (60.55 g/250 mL), and brown rice powder (100.58 g/250 mL). The experimental solutions were prepared by mixing water at room temperature with each ingredient and stirring. The independent variable was the type of ingredient, while the dependent variable was the weight of hollow maize seeds after absorption of the solution. The experimental subject was hollow maize seeds, with a total of six seeds used in the experiment.

- Qualitative Analysis Experiment—Viscous Solution Experiment

In this experiment, the purpose was to verify whether hollow maize seeds have the ability to absorb viscous solutions prepared from different materials. Two groups were created with different ingredients: maize paste powder (50.03 g/250 mL) and lotus root powder (50.05 g/250 mL). The experimental solutions were prepared using 100 °C water mixed with the respective ingredient and then cooled for 1 h prior to the experiment. The independent variable was the type of material, while the dependent variable was the weight of hollow maize seeds after absorption of the solution. The experimental subject was hollow maize seeds, with a total of six seeds used in the experiment.

3.3.3. Experiment Introduction—Experiments on Absorbing Balls Using Qualitative Methods

- Qualitative Analysis Experiment—Viscous Solution Experiment

The purpose of this experiment was to investigate whether the derived structure ball have the ability to absorb viscous solutions and whether they can outperform hollow maize seeds in terms of absorption multiplicity. Two experimental groups were tested using maize paste powder (50.00 g/250 mL) and lotus root powder (49.95 g/250 mL) solutions, respectively. The experimental solutions were prepared by mixing different ingredients with 100 °C water and stirring, and then cooled for 1 h prior to the experiment.

The independent variable in this experiment was the type of material used (maize paste powder, lotus root powder), while the dependent variable was the weight of the derived structure ball after absorption of the solution. The experimental subject was the derived structure ball, with four ball used in each experimental group.

This research may have significant implications for the development of more effective and efficient absorbent materials in the future.

3.3.4. Solution Proportioning for Experimental Design—Quantitative and Qualitative Methods for Studying Hollow Maize Seeds

- Starch Solution Experiment

The design of the starch solution experiment is illustrated in Table 1, where we prepared three different concentrations of starch solutions for the purpose of quantitative testing.

Table 1. Experimental Solution Proportioning in Quantitative Analysis.

Material Weight/Material Classification	Starch 1	Starch 2	Starch 3
Self-weight (g)	80.00	120.00	160.00
Boiling water (mL)	100	100	100

- Multiple Solution Experiment

The design of the multiple solution experiment is presented in Table 2, in which we prepared four distinct solutions for the purpose of qualitative testing. Diverse ratios are established based on the water solubility of the constituents, with the intention of attaining the utmost uniformity in the concentration of the solution.

Table 2. Experimental Solution Proportioning in Qualitative Analysis.

Material Weight/Material Classification	Black Sesame Aleurone	Maize Flour	Lotus Root Starch	Brown Rice Flour
Self-weight (g)	65.02	60.23	60.55	100.58
Boiling water (mL)	250	250	250	250

- Viscous Solution Experiment

The design of the viscous solution experiment is illustrated in Figure 9 and Table 3, wherein we prepared two distinct solutions for the purpose of qualitative testing.

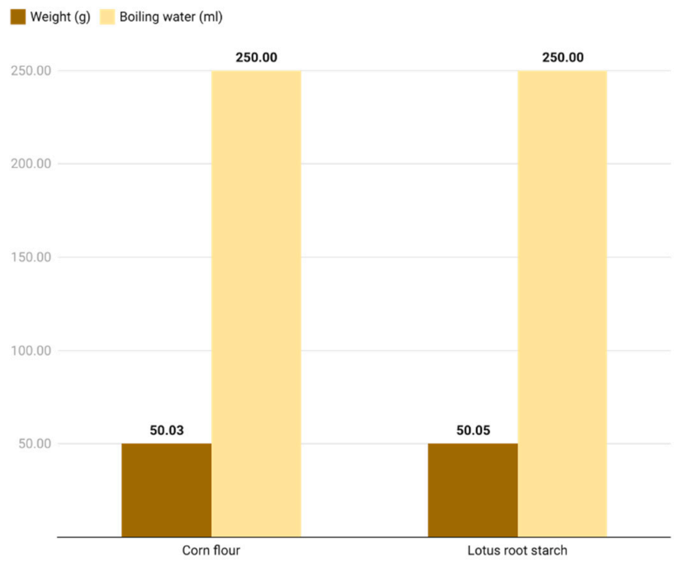

Figure 9. The experimental procedures were carried out utilizing a maize paste solution with high viscosity and a lotus root powder solution.

Table 3. Experimental Solution Proportioning in Qualitative Analysis.

Material Weight/Material Classification	Maize Paste Solution	Lotus Root Powder Solution
Weight (g)	50.03	50.05
Boiling water (mL)	250	250
Cool the solution for 1 h before the experiment.		

3.3.5. Solution Proportioning for Experimental Design—Qualitative Methods for Studying Absorption Balls

For the absorption ball, we designed two sets of distinct solutions to validate the absorption capacity of the ball, as shown in Figure 10 and Table 4, which are utilized for the qualitative investigation of the absorption ball.

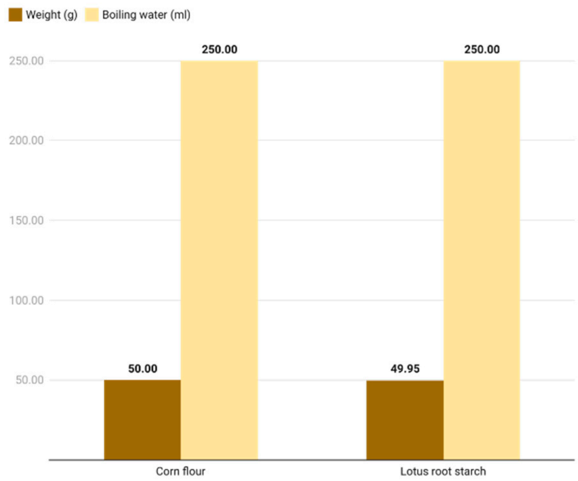

Figure 10. The experimental procedures were carried out utilizing a maize paste solution with high viscosity and a lotus root powder solution.

Table 4. Experimental Solution Proportioning in Qualitative Analysis.

Material Weight/Material Classification	Maize Flour	Lotus Root Starch
Weight (g)	50.00	49.95
Boiling water (mL)	250	250
Cool the solution for 1 h before the experiment.		

3.4. Experimental Procedure

3.4.1. Specific Steps for Starch Solution Experiments

- Preparation of Three Different Concentrations of Solutions

Three different weights of maize starch material, namely, 80 g, 120 g, and 160 g, were taken out and placed in transparent plastic bottles. Then, 100 mL of water was added to each bottle and stirred with the material until completely dissolved.

- Labeling of Eight Maize Kernels

Each maize kernel was labeled to effectively record any changes before and after the experiment and avoid deviation in the experimental data.

- Weighing and Recording of Each Maize Kernel

The weight of each maize kernel was recorded after labeling to ensure experimental rigor.

- Adding Maize Kernels to the Solution

The maize kernels were added to the experimental solution in preparation for the experiment.

- Starting the Stirring Experiment

The plastic bottle was placed on the support structure, and the motor was turned on to start the rotating and stirring experiment.

- Recording of Experimental Process

The entire process of the rotating and stirring experiment was recorded using a cell-phone camera to avoid interference from other factors.

- End of Experiment and Removal of Maize Kernels

The power and motor were turned off at the end of the experiment, and the plastic bottle was removed from the support structure. The cap was opened and the maize kernels were taken out.

- Weighing and Recording of Each Maize Kernel

The removed maize kernels were placed on an electronic scale, and the weight of each kernel was recorded.

- Comparison of Weight Changes and Calculation of Average and Absorption Multiplicity

The average weight of each maize kernel before and after the experiment was calculated, and the relationship between the two multiplicities was determined.

3.4.2. Specific Steps for Multiple Solution Experiments

- Preparation of Four Different Solutions

The appropriate amount of the four materials was taken and placed in a weighed plastic cup. Then, 250 mL of boiling water was added to the materials, and the mixture was stirred until dissolved. The lid was sealed and the solution was left for 5 min. The concentration of the solution particles was observed, and more materials were added until the concentration was similar in all four solutions.

- Labeling of Six Maize Kernels

Each maize kernel was labeled to effectively record any changes before and after the experiment and avoid deviation in the experimental data.

- Remaining Experimental Steps were Consistent with the Above.

3.4.3. Specific Steps for Viscous Solution Experiments

- Preparation of Two Different Solutions

Firstly, 50 g each of maize paste powder and lotus root powder materials were taken, placed in a weighed plastic cup, and mixed with 250 mL of boiling water. The mixture was stirred until completely dissolved, and the lid was sealed and left for 5 min.

- Cooling and Weighing of Two Solutions for One Hour

The plastic bottle containing the two solutions was uncapped and allowed to cool for 1 h to simulate the relatively dry state of liquid food in the human body.

- Weighing and Recording of Six Maize Kernels

The weight of each maize kernel after labeling was recorded to ensure experimental rigor.

- Remaining Experimental Steps were Consistent with the Above.

3.5. Statistical Analysis

During experimental analysis, the arithmetic mean was utilized for statistical analysis. When calculating the mean from relative or average numbers, the key issue is the accurate selection of weights. The arithmetic mean is one of the most fundamental and widely used averages in statistics. It is an important indicator of the overall level and typical characteristics of a phenomenon. It abstracts away the specific differences in the quantity of the phenomenon, reflects the concentrated trend of the phenomenon, and is a representative value [75].

4. Discussion

In this section, we analyze the feasibility of C2C theory in product conceptual design based on the results of qualitative and quantitative experiments. The variations in the absorption capacity of maize seed in the three sets of starch solution experiments are illustrated in Figures 11–13. In the three groups of starch solutions, the performance of maize seed in terms of absorption values is depicted in Figures 14–16. Likewise, we have provided an overview of the results and offered suggestions. Two conceptual design schemes based on C2C theory are compared in more detail in this article and illustrated through experimental results. Finally, we summarize the impact of qualitative and quantitative experiments on demonstrating the influence of C2C theory in product conceptual design through a comparison of experimental data.

4.1. Qualitative and Quantitative Analysis of Hollow Maize Seed Experimental Results

In the evaluation methods of conceptual design, various methods have been proposed, including TOPSIS [76], the weighted product method (WPM) [77], multiple attribute utility theory (MAUT) [78], and the elimination method, among others. Based on the weighted product method, which analyzes the relative weights among interacting objectives, the most competitive design can be obtained. Therefore, in this study, hollow maize seeds were chosen as the experimental object and a series of analyses were conducted based on the weight data changes through before-and-after comparisons. The experiment was divided into quantitative analysis and qualitative analysis, where the former included a starch solution experiment and the latter included multiple solution experiments and viscous solution experiments using different materials to prepare solutions of similar concentrations. The qualitative analysis experiments used the same materials, but the viscosity of the prepared solutions was different.

The purpose of the quantitative analysis experiment was to verify the absorption capacity of hollow maize seeds for different concentrations of solutions prepared with the same material. The purpose of the qualitative analysis experiment was to verify the absorption capacity of hollow maize seeds for solutions of similar concentrations prepared with different materials. Among the qualitative analysis experiments, the multiple solution experiment and the viscous solution experiment used the same materials, but the viscosity of the prepared solutions was different.

Overall, the weighted product method was used to analyze the relative weights of interacting objectives and obtain the most competitive design. The experimental results were based on a series of analyses of weight data changes and included quantitative and qualitative analysis experiments, such as the starch solution experiment, and multiple solution and viscous solution experiments.

4.1.1. Experiment Quantitative Analysis Experiment—Starch Solution Experiment

- Experiment 1

In this experiment, hollow maize seeds were used, and each seed was washed several times with water before the experiment to reduce its weight as much as possible. Then, 80 g of starch was weighed and placed in a transparent plastic bottle. Following this, 100 mL of water was added to the bottle using a measuring cup, and the two were mixed thoroughly before the experiment started. The weight of the hollow maize seeds was recorded over time during the experiment, as shown in Tables 5 and 6. The experimental results are shown in Figures 11 and 14.

Table 5. Starch Solution Experiment 1 data results.

Starch Solution			**After the Experiment (g)**				
100 mL/80 g	**Before Experiment (g)**	**Mean Value (g)**	**5 min**	**10 min**	**15 min**	**20 min**	**25 min**
Maize Seed 1	0.30	0.34	0.52	0.46	0.63	0.66	0.65
Maize Seed 2	0.34		0.43	0.52	0.56	0.60	0.55
Maize Seed 3	0.35		0.43	0.43	0.57	0.64	0.58
Maize Seed 4	0.37		0.56	0.47	0.47	0.64	0.61
Maize Seed 5	0.33		0.48	0.48	0.54	0.54	0.56
Maize Seed 6	0.34		0.49	0.55	0.58	0.58	0.63
Maize Seed 7	0.35		0.42	0.56	0.50	0.54	0.66
Maize Seed 8	0.35		0.56	0.46	0.47	0.67	0.65

Table 6. The average absorption rate and absorption rate of maize seeds in the starch solution at each time period were recorded in Experiment 1.

Mean/Absorption Rate			**After the Experiment (g)**				
100 mL/80 g	**Before Experiment (g)**	**Mean Value (g)**	**5 min**	**10 min**	**15 min**	**20 min**	**25 min**
Maize Seed 1	0.30		Mean value (g)				
Maize Seed 2	0.34						
Maize Seed 3	0.35		0.49	0.49	0.54	0.61	0.61
Maize Seed 4	0.37	0.34					
Maize Seed 5	0.33		Absorption rate				
Maize Seed 6	0.34						
Maize Seed 7	0.35		44%	44%	59%	79%	79%
Maize Seed 8	0.35						

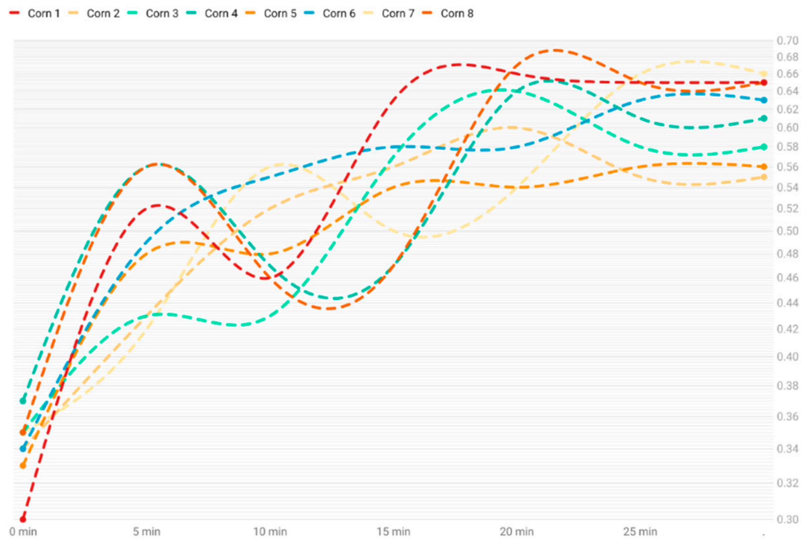

Figure 11. The weight changes of eight hollow dry maize seeds absorbing food in 100 mL/80 g starch solution at different times of the quantitative experiment.

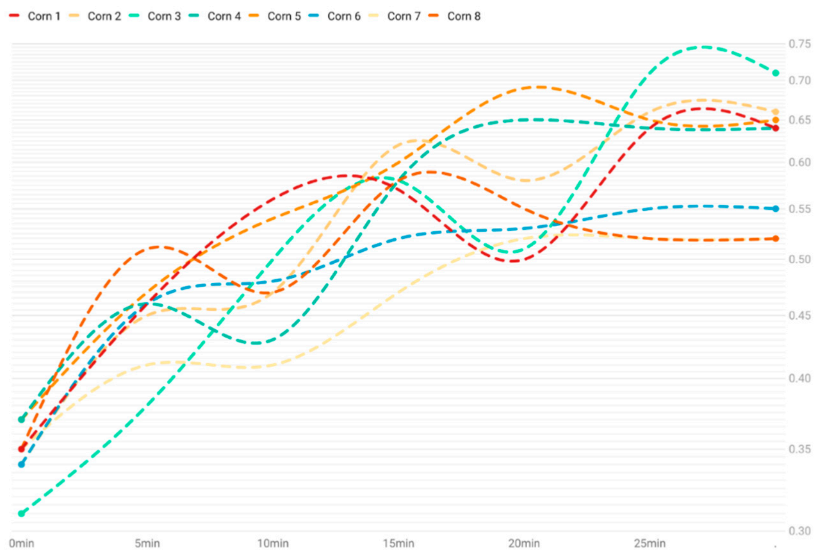

Figure 12. The weight changes of eight hollow dry maize seeds absorbing food in 100 mL/120 g starch solution at different times of the quantitative experiment.

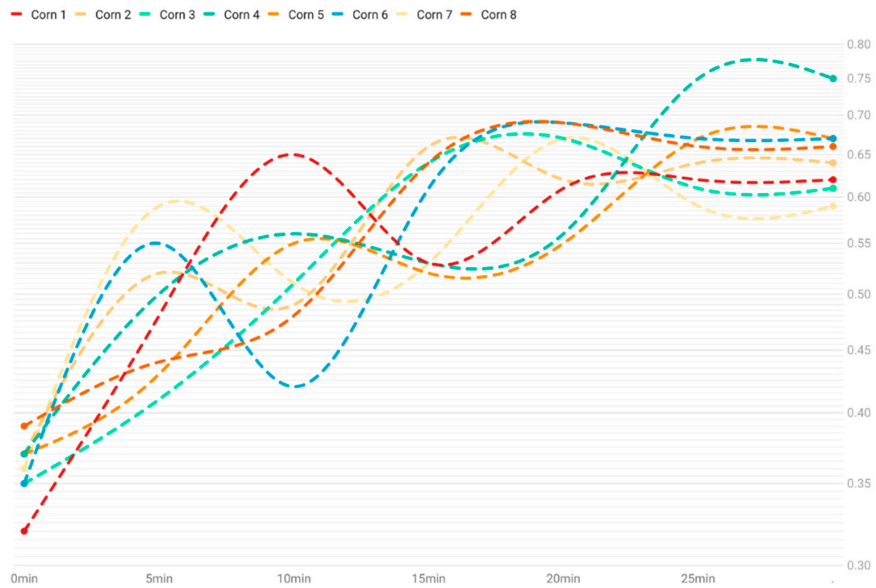

Figure 13. The weight changes of eight hollow dry maize seeds absorbing food in 100 mL/160 g starch solution at different times of the quantitative experiment.

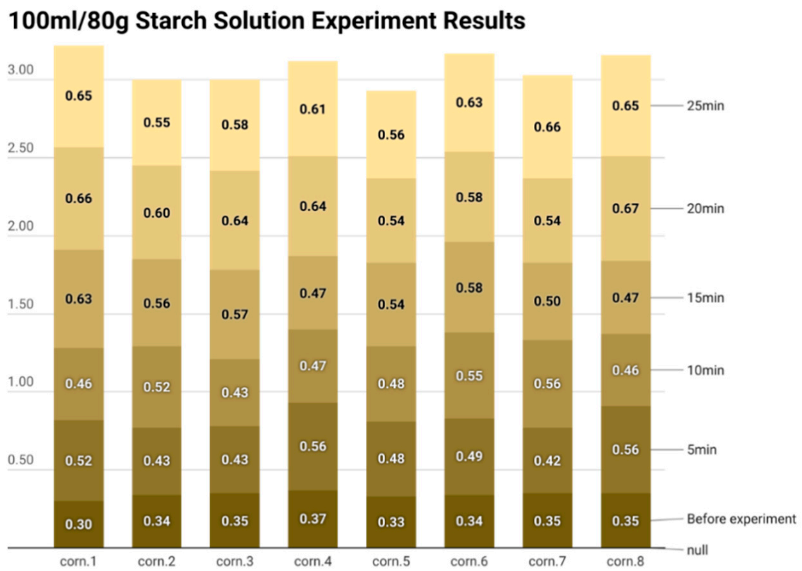

Figure 14. The absorption data of each maize seed in the starch solution in Experiment 1.

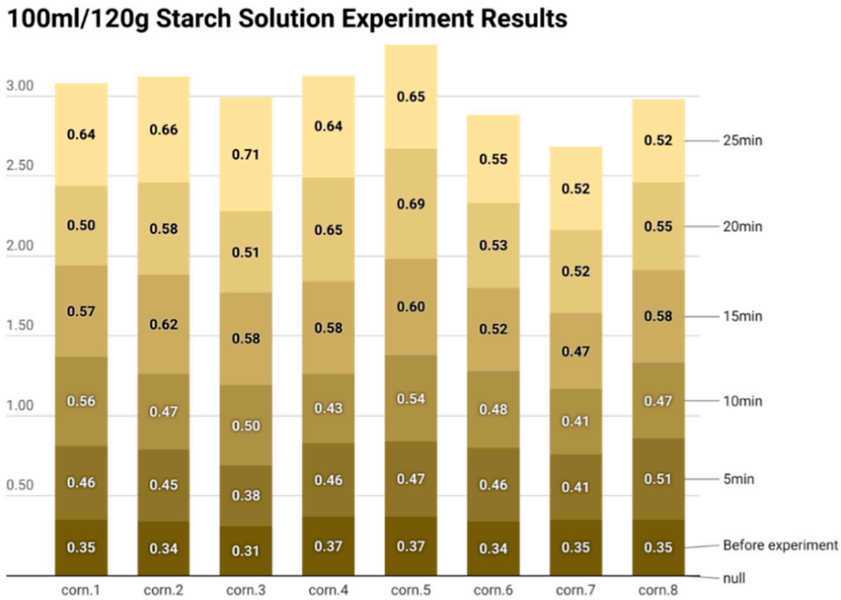

Figure 15. The absorption data of each maize seed in the starch solution in Experiment 2.

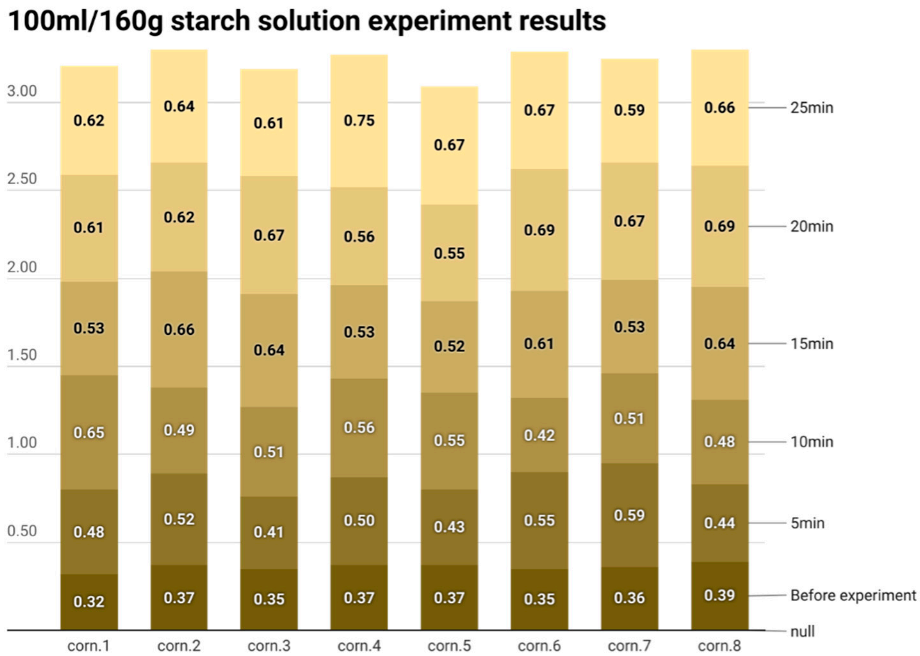

Figure 16. The absorption data of each maize seed in the starch solution in Experiment 3.

- Experiment 2

In this experiment, hollow maize seeds were used, and each seed was washed several times with water before the experiment to reduce its weight as much as possible. Then, 120 g of starch was weighed and placed in a transparent plastic bottle. Following this, 100 mL of water was added to the bottle using a measuring cup, and the two were mixed thoroughly before the experiment started. The weight of the hollow maize seeds was recorded over time during the experiment, as shown in Tables 7 and 8. The experimental results are shown in Figures 12 and 15.

Table 7. Starch Solution Experiment 2 data results.

Starch Solution			After the Experiment (g)				
100 mL/120 g	**Before Experiment (g)**	**Mean Value (g)**	**5 min**	**10 min**	**15 min**	**20 min**	**25 min**
Maize Seed 1	0.35	0.35	0.46	0.56	0.57	0.50	0.64
Maize Seed 2	0.34		0.45	0.47	0.62	0.58	0.66
Maize Seed 3	0.31		0.38	0.50	0.58	0.51	0.71
Maize Seed 4	0.37		0.46	0.43	0.58	0.65	0.64
Maize Seed 5	0.37		0.47	0.54	0.60	0.69	0.65
Maize Seed 6	0.34		0.46	0.48	0.52	0.53	0.55
Maize Seed 7	0.35		0.41	0.41	0.47	0.52	0.52
Maize Seed 8	0.35		0.51	0.47	0.58	0.55	0.52

Table 8. The average absorption rate and absorption rate of maize seeds in the starch solution at each time period were recorded in Experiment 2.

Mean/Absorption Rate			After the Experiment (g)				
100 mL/120 g	**Before Experiment (g)**	**Mean Value (g)**	**5 min**	**10 min**	**15 min**	**20 min**	**25 min**
Maize Seed 1	0.35	0.35	Mean value (g)				
Maize Seed 2	0.34		0.45	0.48	0.57	0.57	0.61
Maize Seed 3	0.31						
Maize Seed 4	0.37						
Maize Seed 5	0.37		Absorption rate				
Maize Seed 6	0.34		29%	37%	63%	63%	74%
Maize Seed 7	0.35						
Maize Seed 8	0.35						

- Experiment 3

In this experiment, hollow maize seeds were used, and each seed was washed several times with water before the experiment to reduce its weight as much as possible. Then, 160 g of starch was weighed and placed in a transparent plastic bottle. Following this, 100 mL of water was added to the bottle using a measuring cup, and the two were mixed thoroughly before the experiment started. The weight of the hollow maize seeds was recorded over time during the experiment, as shown in Tables 9 and 10. The experimental results are shown in Figures 13 and 16.

Table 9. Starch Solution Experiment 3 data results.

Starch Solution			After the Experiment (g)				
100 mL/160 g	**Before Experiment (g)**	**Mean Value (g)**	**5 min**	**10 min**	**15 min**	**20 min**	**25 min**
Maize Seed 1	0.32	0.36	0.48	0.65	0.53	0.61	0.62
Maize Seed 2	0.37		0.52	0.49	0.66	0.62	0.64
Maize Seed 3	0.35		0.41	0.51	0.64	0.67	0.61
Maize Seed 4	0.37		0.50	0.56	0.53	0.56	0.75
Maize Seed 5	0.37		0.43	0.55	0.52	0.55	0.67
Maize Seed 6	0.35		0.55	0.42	0.61	0.69	0.67
Maize Seed 7	0.36		0.59	0.51	0.53	0.67	0.59
Maize Seed 8	0.39		0.44	0.48	0.64	0.69	0.66

Table 10. The average absorption rate and absorption rate of maize seeds in the starch solution at each time period were recorded in Experiment 3.

Mean/Absorption Rate			After the Experiment (g)				
100 mL/160 g	**Before Experiment (g)**	**Mean Value (g)**	**5 min**	**10 min**	**15 min**	**20 min**	**25 min**
Maize Seed 1	0.32	0.36	Mean value (g)				
Maize Seed 2	0.37						
Maize Seed 3	0.35		0.49	0.48	0.49	0.57	0.49
Maize Seed 4	0.37						
Maize Seed 5	0.37		Absorption rate				
Maize Seed 6	0.35						
Maize Seed 7	0.36		36%	33%	36%	58%	36%
Maize Seed 8	0.39						

Using the starch solution experiment as a case study, a quantitative analytical method was employed to design an experiment and verify the absorption capacity of hollow desiccated maize kernels. The findings demonstrated that the hollow desiccated maize kernels exhibited notable absorption capacity for the same ingredient at varying concentrations. Moreover, with an increase in the experimental duration, the absorption rate of the hollow desiccated maize kernels gradually increased, ultimately reaching a steady state.

The results of the experiment indicated that hollow desiccated maize kernels possess a fundamental capacity to absorb everyday food. As time progresses, the absorption ability of the kernels increases, eventually reaching a plateau.

4.1.2. Qualitative Analysis Experiment—Multiple Solutions Experiment

- Experimental investigation of black sesame paste solution

In this experiment, hollow desiccated maize kernels were used, and each kernel was washed multiple times before the experiment to minimize its weight.

Firstly, 65.02 g of black sesame paste powder was weighed and placed in a transparent plastic bottle. Then, 250 mL of boiling water was added to the bottle using a measuring cup, and the two were mixed thoroughly and allowed to stand for 5 min. The hollow desiccated maize kernels were then placed into the bottle, and the experiment was started. The experimental results are shown in Table 11.

Table 11. Experimental Data of Black Sesame Paste Solution.

Black Sesame Aleurone Experimental Subjects	Before Experiment (g)	Mean Value (g)	10 min Later	After the Experiment (g)	Mean Value (g)	Absorption Rate
Maize 1	0.27	0.34	-	0.50	0.57	68%
Maize 2	0.34			0.58		
Maize 3	0.32			0.50		
Maize 4	0.35			0.53		
Maize 5	0.37			0.68		
Maize 6	0.36			0.65		

- Experimental investigation of maize paste solution

Firstly, 60.23 g of maize paste powder was weighed, and 250 mL of boiling water was added using a graduated cylinder. The two components were thoroughly mixed and allowed to stand for 5 min. The hollow desiccated maize kernels were then added to the mixture, and the experiment was initiated. The experimental outcomes are presented in Table 12.

Table 12. Experimental Data of Maize Paste Solution.

Maize Paste Experimental Subjects	Before Experiment (g)	Mean Value (g)	10 min Later	After the Experiment (g)	Mean Value (g)	Absorption Rate
Maize Seed 1	0.26	0.34	-	0.56	0.64	88%
Maize Seed 2	0.36			0.66		
Maize Seed 3	0.32			0.62		
Maize Seed 4	0.34			0.71		
Maize Seed 5	0.37			0.61		
Maize Seed 6	0.36			0.65		

- Experimental investigation of lotus root powder solution

Before the experiment, each maize kernel was washed multiple times to remove any residues inside and minimize the weight of the dry maize kernels. Then, 60.55 g of lotus root powder was weighed, and 250 mL of boiling water was added using a measuring cup. The two were mixed thoroughly and allowed to stand for 5 min. The experimental results are shown in Table 13.

Table 13. Experimental Data of Lotus Root Starch Solution.

Lotus Root Powder Experimental Subjects	Before Experiment (g)	Mean Value (g)	10 min Later	After the Experiment (g)	Mean Value (g)	Absorption Rate
Maize Seed 1	0.27	0.33	-	0.59	0.63	91%
Maize Seed 2	0.35			0.62		
Maize Seed 3	0.32			0.59		
Maize Seed 4	0.34			0.65		
Maize Seed 5	0.36			0.65		
Maize Seed 6	0.36			0.65		

- Experimental investigation of brown rice flour solution

Before the experiment, the cleaning steps of the previous experiment were repeated. Then, 100.58 g of brown rice flour was weighed, and 250 mL of boiling water was added using a measuring cup. The two were mixed thoroughly and allowed to stand for 5 min. The experimental results are shown in Table 14.

Table 14. Experimental Data of Brown Rice Flour Solution.

Maize Flour Experimental Subjects	Before Experiment (g)	Mean Value (g)	10 min Later	After the Experiment (g)	Mean Value (g)	Absorption Rate
Maize Seed 1	0.28	0.34	-	0.48	0.52	53%
Maize Seed 2	0.36			0.47		
Maize Seed 3	0.31			0.45		
Maize Seed 4	0.35			0.71		
Maize Seed 5	0.37			0.51		
Maize Seed 6	0.36			0.50		

During the qualitative study, we conducted experiments using four different solutions to explore the absorption capacity of corn seeds for various foods, with the results illustrated in Figure 17.Despite the variation in the proportions of the four materials, the phenomenon observed in Figure 18 still occurred in the comparison of solution concentrations.

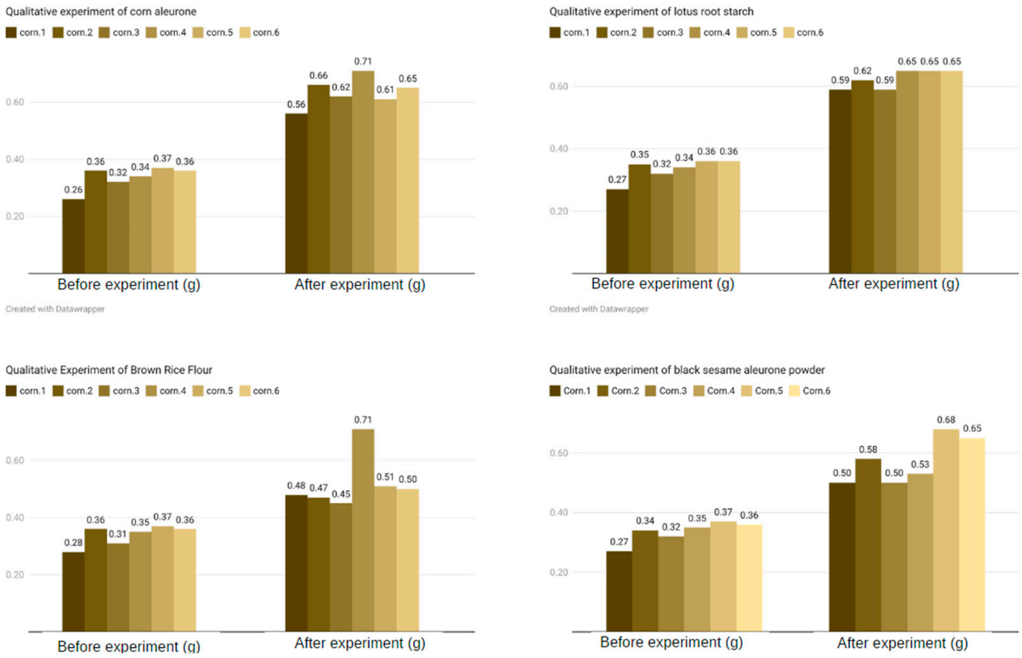

Figure 17. In the qualitative experiment, the absorption capacity of hollow maize seed was tested by four different solutions, aiming to investigate the absorption ability of the conceptual product in various solutions.

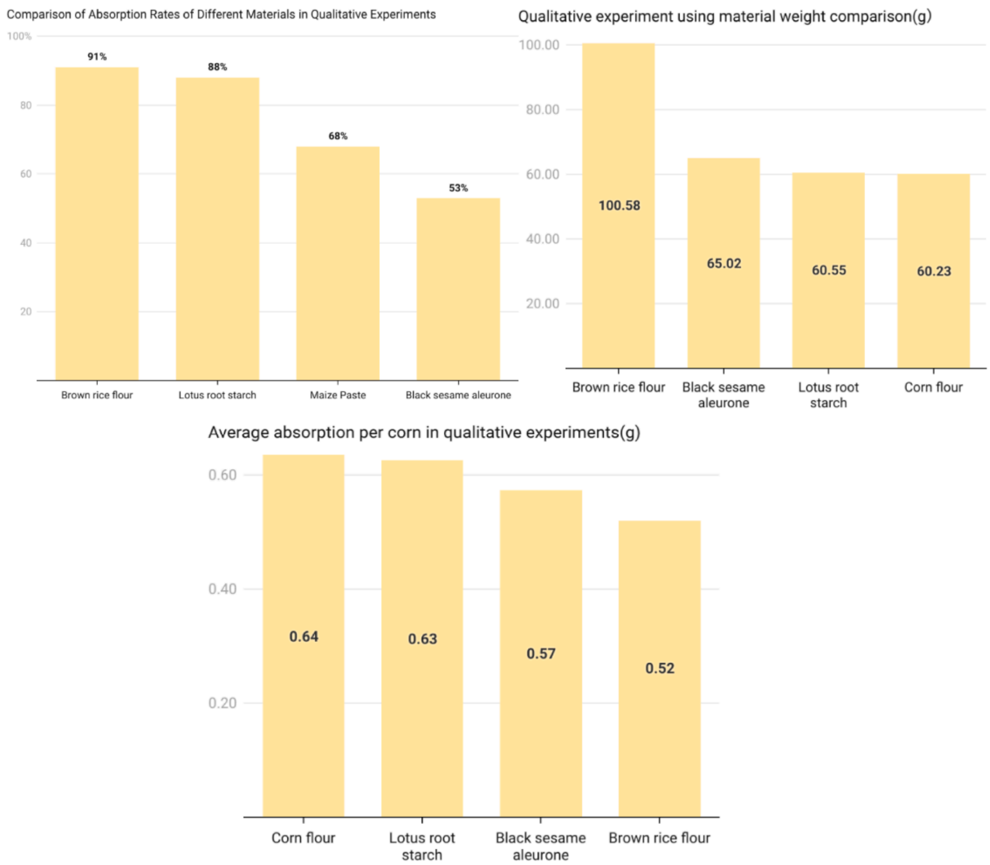

Figure 18. In the qualitative experiment, a comparison was made of the four different qualitative experimental data, and a summary was made of the material weight used in the experimental solutions, the average absorption of the conceptual product in different solutions, and the absorption rate in different solutions.

In the experiment, four distinct solutions were utilized to simulate various food sources in human dietary practices. The results of the qualitative experiment are presented in Table 15.The results of the experiment affirmed that hollow desiccated maize kernels have the capability to absorb diverse food sources and that the absorption rate is concentration dependent. Furthermore, the experiment demonstrated that the absorption rate of hollow maize kernels is positively correlated with the viscosity of the solution. This study provides empirical evidence for the potential use of hollow desiccated maize kernels as a food absorbent in a variety of applications. The outcomes of this research may facilitate the advancement of novel food technologies and formulations in the future.

Table 15. Summary of Qualitative Experiment Results.

Summary of four aspects of qualitative experimental research
Used material weight (g):
Brown rice flour (100.58) > Black sesame aleurone (65.02) > Lotus root flour (60.55) > Maize paste (60.23)
Solution viscosity:
Maize paste solution > Lotus root flour solution > Black sesame paste solution > Brown rice flour solution
Average absorption (g):
Maize paste solution (0.64) > Lotus root starch solution (0.63) > Black sesame paste solution (0.57) > Brown rice flour solution (0.52)
Absorption rate:
Maize paste solution (91%) > Lotus root starch solution (88%) > Black sesame paste solution (68%) > Brown rice flour solution (53%)

4.1.3. Qualitative Analysis Experiment—Viscous Solution Experiment

- Experiment of viscous maize paste solution

The previous experiment has confirmed that the absorption rate of dried maize kernels is higher in solutions with higher viscosity. In this round of experiments, the absorption capacity of dried maize kernels in solutions with higher viscosity will be further investigated by extending the experimental duration.

Before the experiment, the maize kernels were washed and dried. Then, 50.03 g of maize paste powder was weighed, and 250 mL of boiling water was measured using a graduated cylinder. The two were thoroughly mixed and allowed to cool for 60 min to increase the viscosity of the solution.

The increased viscosity of the solution was achieved by allowing it to cool and settle, which is expected to enhance the absorption ability of dried maize kernels, The results are shown in Table 16.

Table 16. Experimental Data of Viscous Maize Paste Solution.

Viscous Maize Paste Solution Experimental Subjects	**Before Experiment (g)**	**Mean Value (g)**	**25 min Later**	**After the Experiment (g)**	**Mean Value (g)**	**Absorption Rate**
Maize Seed 1	0.28	0.35	-	0.56	0.64	83%
Maize Seed 2	0.37			0.70		
Maize Seed 3	0.34			0.53		
Maize Seed 4	0.37			0.64		
Maize Seed 5	0.38			0.72		
Maize Seed 6	0.38			0.67		

- Experiment of Viscous Lotus Root Starch Solution

Prior steps to the experiment were carried out as in the previous trial. Specifically, 50.05 g of lotus root powder was weighed and mixed thoroughly with 250 mL of boiling water, as measured by a volumetric flask. The resulting mixture was left to cool for 60 min, during which time the solution's viscosity increased due to its settling. This procedure was performed to achieve a higher level of homogeneity in the solution and to ensure that the experiment was carried out under standardized conditions, The experimental results are shown in Table 17.

Table 17. Experimental Data of Viscous Lotus Root Starch Solution.

Viscous Lotus Root Starch Solution Experimental Subjects	Before Experiment (g)	Mean Value (g)	25 min Later	After the Experiment (g)	Mean Value (g)	Absorption Rate
Maize Seed 1	0.27	0.34	-	0.59	0.63	85%
Maize Seed 2	0.36			0.69		
Maize Seed 3	0.31			0.52		
Maize Seed 4	0.36			0.67		
Maize Seed 5	0.37			0.62		
Maize Seed 6	0.37			0.71		

In contrast to previous experiments, the current study on viscous solutions required an adjustment of the experimental time to 25 min corresponding to the extended retention time of solid foods during human digestion.

- Conclusion:

The results of the second experiment showed that hollow dried maize kernels had a noteworthy ability to absorb high viscosity solutions approximately equal to their own weight.

4.1.4. Derivative Concept Product Absorption Experiment

The experiment employed a small ball derivative structure that was designed based on dry maize kernels, with a total of four balls. Subsequent analysis was conducted by comparing the weight before and after the experiment. Two types of food were used for the experiment under the same conditions as the previous round, with the aim of verifying whether the ball derivative structure could increase its self-absorption rate while ensuring that the absorbed food does not flow out. The goal was to investigate the effectiveness of the ball derivative structure in enhancing its self-absorption ability.

- Experiment of viscous maize paste solution

Before the experiment, four small balls were labeled with serial numbers and weighed individually for subsequent weight comparison. Then, 50.00 g of maize starch was weighed, and 250 mL of boiling water was measured with a measuring cup. The two were thoroughly mixed and allowed to cool for 60 min, The experimental results are shown in Table 18.

Table 18. Experimental Data of Viscous Maize Paste Solution.

Viscous Maize Paste Solution Experimental Subjects	Before Experiment (g)	Mean Value (g)	25 min Later	After the Experiment (g)	Mean Value (g)	Absorption Rate
Ball 1	1.20	1.19	-	5.65	5.34	349%
Ball 2	1.18			5.22		
Ball 3	1.21			4.93		
Ball 4	1.15			5.54		

- Experiment of viscous lotus root starch solution

The pre-experimental procedures were identical to the previous experiment. Then, 49.95 g of lotus root powder was weighed, and 250 mL of boiling water was measured using a graduated cylinder. The two were thoroughly mixed and allowed to cool for 60 min, The experimental results are shown in Table 19 and Figure 19.

Table 19. Experimental Data of Viscous Lotus Root Starch Solution.

Viscous Lotus Root Starch Solution / Experimental Subjects	Before Experiment (g)	Mean Value (g)	25 min Later	After the Experiment (g)	Mean Value (g)	Absorption Rate
Ball 1	1.21	1.19	-	2.84	3.15	165%
Ball 2	1.18			2.71		
Ball 3	1.21			3.72		
Ball 4	1.15			3.33		

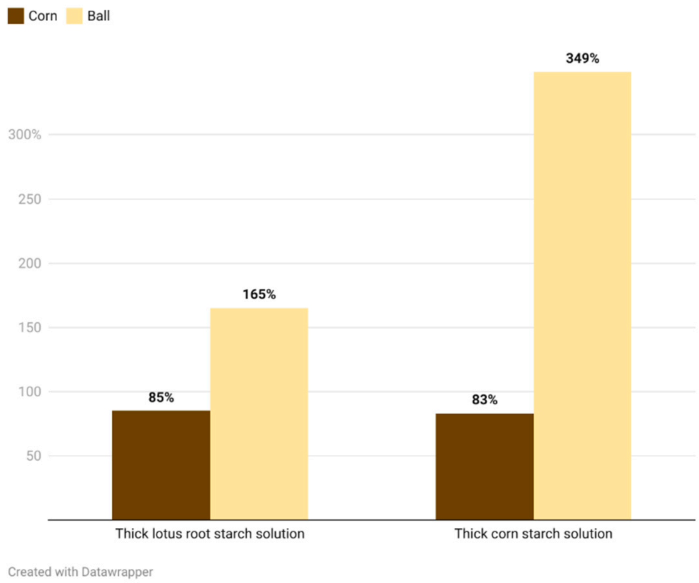

Figure 19. A comparison was made between the absorption rates of the derivative small balls of the conceptual product and the hollow dry maize kernels of the conceptual product in viscous lotus root powder solution and viscous maize starch solution.

- Conclusions:

This round of experiments confirmed the absorptive ability of the small ball derivative structure that was designed based on maize kernels. Under conditions identical to the previous experiment, the absorptive rate of the small ball derivative structure was significantly improved.

4.2. Analysis of Experimental Results

In this study, a series of experiments were conducted to investigate the absorbency of hollow maize seeds under different conditions.

1. Firstly, the absorbency of the same material at different concentrations on hollow maize seeds was quantitatively studied.
2. Secondly, the absorbency of four different solutions on hollow maize seeds was qualitatively studied.
3. Thirdly, the absorbency of two high-viscosity solutions on hollow maize seeds was qualitatively studied.
4. Finally, the absorbency of two high-viscosity solutions on small ball derivatives based on hollow maize seeds was qualitatively studied.

The starch solution experiment confirmed that hollow maize seeds have absorbency, and the absorbed weight increases over time and eventually stabilizes.

The multi-solution experiment showed that hollow maize seeds can absorb solutions of different viscosities. In addition, the experimental conclusion is that the absorbency of hollow maize seeds in low-viscosity solutions increases with the increase of solution concentration.

The viscous solution experiment confirmed the absorbency of hollow maize seeds to high-concentration viscous solutions. These experiments collectively demonstrate the ability of hollow maize seeds to absorb solutions in different states.

Theoretically, multiple solutions can be likened to different types of food consumed by humans, while the stirred experimental environment can be likened to the human digestive process. Therefore, hollow maize seeds may produce similar effects in the human body.

The structural derivative experiment confirmed that small ball derivatives based on hollow maize seeds have absorbency. Moreover, the experiment indicated that the absorbency rate of the small balls was higher than that of the hollow maize seeds.

In conclusion, our study provides comprehensive evidence for the absorbent properties of hollow maize seeds under various conditions, including different types of solutions and concentrations. The results of this study could have potential implications for various fields, which can reference areas like food processing and diet control.

Furthermore, a comparison of the viscous solution experiments and the derivative structure experiments is presented in Table 20.

Table 20. Comparison of Absorption Rate of Different Products in Viscous solution.

Comparison of the two concept products			
Viscous Maize Paste Solution		**Viscous Lotus Root Starch Solution**	
Experimental subjects/Absorption rate			
Maize Seed	**Ball**	**Maize Seed**	**Ball**
83%	349%	85%	165%

According to Table 20, the experimental results of the derivative structure demonstrate that the design of the small ball prototype has effectively improved the absorption rate compared to the hollow maize seed, further proving the rationality of the small ball derivative structure.

4.3. Discussion

In this investigation, we not only adhered to the three fundamental principles of C2C theory in our conceptual design, but also thoroughly integrated these principles—waste as a resource, utilization of renewable energy, and respect for diversity—into the structure of both quantitative and qualitative experimental setups.

In the quantitative experiments, we selected varying concentrations of starch solutions, examining their absorption by our concept product. This approach aimed to evaluate the design's capacity to absorb different concentrations of a single food type. Starch, a renewable natural resource, aligns with the C2C principle of utilizing renewable energy sources. Its circulation within the ecosystem resembles that of biological nutrients, emphasizing the waste-as-resource principle. In the qualitative experiments, we designed multiple solutions to assess the product's absorption capabilities, simulating a diverse array of foods consumed in daily life to approximate real-world eating environments. The experimental design of both the qualitative and quantitative studies align with the C2C principle of celebrating diversity.

In summary, the design of these experiments not only verifies the feasibility of the concept product but also reflects the core tenets of C2C theory. By incorporating the three principles of C2C theory into our experimental design, we seek to ensure that the concept product fulfills its intended function while adhering to the standards of environmental protection and sustainable development.

Furthermore, in the practical component of our research, we designed a concept product to evaluate its weight-loss properties. This aspect of the study may overlap with certain medical clinical investigations, which we acknowledge. Our study primarily focuses on evaluating the conceptual design of a product guided by C2C theory, and the practical research emphasizes assessing the feasibility of the conceptual design through theoretical investigations. It is important to note that this study addresses only a portion of the weight-loss process through product conceptual design within a laboratory setting. There remain numerous specialized issues in the medical field that we are currently unable to address, which is a limitation of our research.

In future studies, we plan to actively collaborate with researchers in the medical field to obtain relevant research qualifications and subsequently concentrate on addressing specialized issues in the realm of weight loss. This interdisciplinary approach will ensure a more comprehensive understanding of the concept product's potential in real-world applications and its overall impact on health and well-being. By integrating insights from multiple fields, we aim to create a product that not only adheres to the principles of C2C design but also addresses the complex challenges associated with weight loss and human health. Future studies may contemplate adopting diverse approaches such as integrating control groups, repositioning experimental materials, or deploying live animal experiments to better reflect qualitative and quantitative experimental environments under real-world conditions.

5. Conclusions

This paper elucidates the practicability of applying Cradle to Cradle (C2C) theory in conceptual product design and also evaluates the efficacy of amalgamating theory and practice in sustainable conceptual design. This study exemplifies how natural and renewable resources can be innovatively utilized to engender novel products with specific functional attributes, which is congruent with the tenets of sustainable concept design, accentuating the use of eco-friendly materials and efficacious production processes that abate waste and environmental impact.

Qualitative and quantitative experiments were implemented to ascertain the viability of the concept product by scrutinizing the absorption properties of hollow corn seeds. As evidenced by our experiments, the capacity of hollow corn seeds to assimilate disparate types and concentrations of solutions intimates that these seeds can be exploited as a natural and renewable resource that can be utilized for a diverse range of applications. For instance, the absorption properties of hollow maize seeds could be employed to fashion novel food products or constituents with specific functional properties, such as augmentation of texture or improved nutrient assimilation.

Altogether, this study furnishes a comprehensive inquiry into the absorption properties of hollow maize seeds under sundry conditions, which can proffer a constructive impact on the evolution of derivative product designs. Moreover, experiments on the derivative concept corroborated the extension of our theoretical practice. The outcomes of this study make a salutary contribution to the advancement of derivative product design, elucidating how C2C theory can be harnessed to fabricate innovative products that are both functional and sustainable. This study lays the groundwork for future research as it underscores the significance of considering the sustainability of product development at the conceptual stage. By assimilating the tenets of sustainable conceptual design, designers and manufacturers can engender products that meet consumer needs while safeguarding the environment and conserving natural resources. These findings also underscore the importance of introducing C2C theory at the concept stage in research on product development. Although C2C theory has a broader application in terms of landing products or supporting decision making, it still plays a pivotal role in ameliorating the product design ecosystem as a methodology for refining product concepts.

Notwithstanding, we concede the constraints of our methodology. Firstly, our study was conducted in a laboratory setting, instead of an actual production line or product use environment. While this facilitates control over other factors that may affect qualitative and quantitative experiments, it may not precisely emulate the scenarios and equipment conditions of qualitative and quantitative experiments in the industry. Secondly, we acknowledge the limitations regarding the analysis of energy consumption for the product. Throughout the C2C cycle, energy dynamics play a crucial role, with different states of the product form and manufacturing methods and processes leading to varying levels of energy consumption. While energy loss is not explicitly emphasized as a key principle of C2C theory, it does advocate for reduced energy loss throughout the overall cycle, which our research also recognizes. Consequently, our study's focus on the conceptual design of the product based on C2C theory and the evaluation process utilizing qualitative and quantitative experiments has inherent limitations in addressing energy consumption and cycles.

Given the constraints of the laboratory environment, our study has limited capabilities in evaluating energy consumption and cycles throughout the concept product's life. This challenge parallels the development of concept vehicles, where the steps required to progress from proof of concept to mass production involve substantial cost and energy optimizations.

Similarly, our research faces the same challenges. In our subsequent research, we will continue to strengthen the analysis of energy consumption across various aspects of product forms guided by C2C theory, in order to enhance the practical implementation of the C2C approach. By addressing the limitations of energy consumption and cycle evaluation, we aim to ensure that our research adheres to the principles of environmental sustainability and contributes to the advancement of C2C theory in real-world applications.

Moreover, the integration of emerging technologies such as artificial intelligence (AI) represents a promising avenue for advancing sustainable design theory and its intersection with technological factors. For instance, AI technology can provide a high-quality simulation environment for sustainable design and even product design based on C2C theory. By leveraging digital simulation technology and cutting-edge innovations, researchers can bridge the gap between the conceptual design stage and the product development phase. This approach enables more effective evaluation of sustainable design's efficacy and applicability, offering additional development paths for real-world product development and allowing sustainable design to thrive in diverse contexts.

Our research explores the research approach of inferring design possibilities from the perspective of sustainable design, based on the assumption of the referred sustainable materials that are safe, harmless, while sharing required physical characters. Obviously, the contribution of this study lies in exploring the effectiveness of a sustainable design method rather than explicitly guidance in clinical medicine or healthcare. We believe that research at this stage should not be used as a basis or guidance for medical or healthcare production and rehabilitation without strict clinical trials with rigorous health and safety permits.

In conclusion, while our current study has its limitations, future research will explore more comprehensive approaches, incorporating advanced technologies and more extensive energy consumption analyses, to ensure that C2C theory can be successfully applied to practical, sustainable product development.

Author Contributions: Methodology, X.Z. and X.X.; Software, X.L.; Validation, X.L. and J.X.; Writing—original draft, X.L. and Y.Z.; Supervision, D.-B.L.; Project administration, D.-B.L.; Funding acquisition, D.-B.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially supported by National Social Science Foundation of China grant number 21WZSB032, the Humanity and Social Science Youth Foundation of the Ministry of Education of China grant number 18YJCZH249, the Guangzhou Science and Technology Planning Project grant number 201904010241, the Humanity Design and Engineering Research Team grant number 263303306 and the National Natural Science Foundation of China grant number 52008114.

Institutional Review Board Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ibbotson, S.; Kara, S. A framework for determining the life time energy consumption of a product at the concept design stage. *Procedia Cirp* **2018**, *69*, 704–709.
2. Ahmad, S.; Wong, K.Y.; Tseng, M.L.; Wong, W.P. Sustainable product design and development: A review of tools, applications and research prospects. *Resour. Conserv. Recycl.* **2018**, *132*, 49–61.
3. Chofreh, A.G.; Goni, F.A.; Klemeš, J.J.; Moosavi, S.M.S.; Davoudi, M.; Zeinalnezhad, M. COVID-19 shock: Development of strategic management framework for global energy. *Renew. Sustain. Energy Rev.* **2021**, *139*, 110643.
4. Sari, E.; Ma'aram, A.; Shaharoun, A.M.; Chofreh, A.G.; Goni, F.A.; Klemeš, J.J.; Marie, I.A.; Saraswati, D. Measuring sustainable cleaner maintenance hierarchical contributions of the car manufacturing industry. *J. Clean. Prod.* **2021**, *312*, 127717.
5. Rebitzer, G.; Ekvall, T.; Frischknecht, R.; Hunkeler, D.; Norris, G.; Rydberg, T.; Schmidt, W.-P.; Suh, S.; Weidema, B.P.; Pennington, D.W. Life cycle assessment: Part 1: Framework, goal and scope definition, inventory analysis, and applications. *Environ. Int.* **2004**, *30*, 701–720.
6. Anderson, D.M. *Design for Manufacturability: How to Use Concurrent Engineering to Rapidly Develop Low-Cost, High-Quality Products for Lean Production*; Productivity Press: New York, NY, USA, 2020.
7. Han, J.; Jiang, P.; Childs, P. Metrics for measuring sustainable product design concepts. *Energies* **2021**, *14*, 3469.
8. Pahl, G.; Beitz, W. *Engineering Design*; Wallace, K., Ed.; The Design Council: London, UK, 1973.
9. McDonough, W.; Braungart, M. *Cradle to cradle: Remaking the Way We Make Things*; North Point Press: New York, NY, USA, 2010.
10. Toxopeus, M.E.; De Koeijer, B.; Meij, A. Cradle to cradle: Effective vision vs. efficient practice? *Procedia Cirp* **2015**, *29*, 384–389.
11. Finkbeiner, M.; Schau, E.M.; Lehmann, A.; Traverso, M. Towards life cycle sustainability assessment. *Sustainability* **2010**, *2*, 3309–3322.
12. Finkbeiner, M. Carbon footprinting—Opportunities and threats. *Int. J. Life Cycle Assess.* **2009**, *14*, 91–94.
13. Berger, M.; Finkbeiner, M. Water footprinting: How to address water use in life cycle assessment? *Sustainability* **2010**, *2*, 919–944.
14. *ISO 14040*; International Standard. Environmental Management-Life Cycle Assessment-Principles and Framework. International Organisation for Standardization: Geneva, Switzerland, 2006.
15. Manfredi, S.; Allacker, K.; Pelletier, N.; Chomkhamsri, K.; de Souza, D.M. *Product Environmental Footprint (PEF) Guide*; European Commission—Joint Research Centre: Ispra, Italy, 2012.
16. Lehmann, A.; Bach, V.; Finkbeiner, M. EU product environmental footprint—Mid-term review of the pilot phase. *Sustainability* **2016**, *8*, 92.
17. Minkov, N.; Bach, V.; Finkbeiner, M. Characterization of the cradle to cradle certified™ products program in the context of eco-labels and environmental declarations. *Sustainability* **2018**, *10*, 738.
18. Bach, V.; Minkov, N.; Finkbeiner, M. Assessing the ability of the Cradle to Cradle Certified™ Products Program to reliably determine the environmental performance of products. *Sustainability* **2018**, *10*, 1562.
19. Mehrad, A.; Zangeneh, M.H.T. Comparison between qualitative and quantitative research approaches: Social sciences. *Int. J. Res. Educ. Stud. Iran* **2019**, *5*, 1–7.
20. Homburg, C.; Schwemmle, M.; Kuehnl, C. New product design: Concept, measurement, and consequences. *J. Mark.* **2015**, *79*, 41–56.
21. Poetz, M.K.; Schreier, M. The value of crowdsourcing: Can users really compete with professionals in generating new product ideas? *J. Prod. Innov. Manag.* **2012**, *29*, 245–256.
22. Bloch, P.H. Product design and marketing: Reflections after fifteen years. *J. Prod. Innov. Manag.* **2011**, *28*, 378–380.
23. Srinivasan, R.; Lilien, G.L.; Rangaswamy, A.; Pingitore, G.M.; Seldin, D. The total product design concept and an application to the auto market. *J. Prod. Innov. Manag.* **2012**, *29*, 3–20.
24. Xu, Z.; Wang, H. Managing multi-granularity linguistic information in qualitative group decision making: An overview. *Granul. Comput.* **2016**, *1*, 21–35.
25. Nguyen, H.-T.; Dawal, S.Z.M.; Nukman, Y.; Aoyama, H. A hybrid approach for fuzzy multi-attribute decision making in machine tool selection with consideration of the interactions of attributes. *Expert Syst. Appl.* **2014**, *41*, 3078–3090.
26. Khalid, H.M.; Helander, M.G. Customer emotional needs in product design. *Concurr. Eng.* **2006**, *14*, 197–206.
27. Jiang, S.; Li, J. Research of the effectual action unit–based inverse method for solving the functional structure of design history. *Adv. Mech. Eng.* **2016**, *8*, 1687814016663805.
28. Tiwari, V.; Jain, P.K.; Tandon, P. Product design concept evaluation using rough sets and VIKOR method. *Adv. Eng. Inform.* **2016**, *30*, 16–25.
29. Atlason, R.S.; Stefansson, A.S.; Wietz, M.; Giacalone, D. A rapid Kano-based approach to identify optimal user segments. *Res. Eng. Des.* **2018**, *29*, 459–467.
30. Cantamessa, M.; Montagna, F.; Cascini, G. Design for innovation–A methodology to engineer the innovation diffusion into the development process. *Comput. Ind.* **2016**, *75*, 46–57.
31. Zhang, H.; Han, X.; Li, R.; Qin, S.; Ding, G.; Yan, K. A new conceptual design method to support rapid and effective mapping from product design specification to concept design. *Int. J. Adv. Manuf. Technol.* **2016**, *87*, 2375–2389.

32. Huo, Y.-L.; Hu, X.-B.; Chen, B.-Y.; Fan, R.-G. A Product Conceptual Design Method Based on Evolutionary Game. *Machines* **2019**, *7*, 18.
33. Zhou, X.; Wu, Y.; Polochova, V. Product Conceptual Design Method Based on Intuitionistic Fuzzy Binary Semantics Group Decision Making. *J. Serv. Sci. Manag.* **2019**, *12*, 742.
34. Hu, Z.; Rao, C.; Tao, C.; Childs, P.R.; Zhao, Y. A case-based decision theory based process model to aid product conceptual design. *Clust. Comput.* **2019**, *22*, 10145–10162.
35. Li, X.; Jiang, Z.; Guan, Y.; Li, G.; Wang, F. Fostering the transfer of empirical engineering knowledge under technological paradigm shift: An experimental study in conceptual design. *Adv. Eng. Inform.* **2019**, *41*, 100927.
36. Chunhua, F.; Shi, H.; Guozhen, B. A group decision making method for sustainable design using intuitionistic fuzzy preference relations in the conceptual design stage. *J. Clean. Prod.* **2020**, *243*, 118640.
37. Elsen, C.; Häggman, A.; Honda, T.; Yang, M.C. Representation in Early Stage Design: An Analysis of the Influence of Sketching and Prototyping in Design Projects. In Proceedings of the International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Chicago, IL, USA, 12–15 August 2012; pp. 737–747.
38. Gelo, O.; Braakmann, D.; Benetka, G. Quantitative and qualitative research: Beyond the debate. *Integr. Psychol. Behav. Sci.* **2008**, *42*, 266–290.
39. Raynor, D.; Blenkinsopp, A.; Knapp, P.; Grime, J.; Nicolson, D.; Pollock, K.; Dorer, G.; Gilbody, S.; Dickinson, D.; Maule, A. A systematic review of quantitative and qualitative research on the role and effectiveness of written information available to patients about individual medicines. *Health Technol. Assess.* **2007**, *11*, 1–177.
40. Firestone, W.A. Meaning in method: The rhetoric of quantitative and qualitative research. *Educ. Res.* **1987**, *16*, 16–21.
41. Barnham, C. Quantitative and qualitative research: Perceptual foundations. *Int. J. Mark. Res.* **2015**, *57*, 837–854.
42. Binder, T.; De Michelis, G.; Ehn, P.; Jacucci, G.; Linde, P. *Design Things*; MIT Press: Cambridge, MA, USA, 2011.
43. Verganti, R. Design, meanings, and radical innovation: A metamodel and a research agenda. *J. Prod. Innov. Manag.* **2008**, *25*, 436–456.
44. Ankrah, N.A.; Manu, E.; Booth, C. Cradle to cradle implementation in business sites and the perspectives of tenant stakeholders. *Energy Procedia* **2015**, *83*, 31–40.
45. Braungart, M.; Mcdonough, W.; Bollinger, A. Cradle-to-cradle design: Creating healthy emissions—A strategy for eco-effective product and system design. *J. Clean. Prod.* **2007**, *15*, 1337–1348.
46. Lin, C.-W.; Jeng, S.-Y.; Tseng, M.-L.; Tan, R. A cradle-to-cradle analysis in the toner cartridge supply chain using fuzzy recycling production approach. *Manag. Environ. Qual.* **2019**, *30*, 329–345. https://doi.org/10.1108/meq-05-2018-0088.
47. Lima, M.S.S.; Hajibabaei, M.; Hesarkazzazi, S.; Sitzenfrei, R.; Buttgereit, A.; Queiroz, C.; Haritonovs, V.; Gschosser, F. Determining the Environmental Potentials of Urban Pavements by Applying the Cradle-to-Cradle LCA Approach for a Road Network of a Midscale German City. *Sustainability* **2021**, *13*, 12487. https://doi.org/10.3390/su132212487.
48. Kopnina, H. Circular economy and Cradle to Cradle in educational practice. *J. Integr. Environ. Sci.* **2018**, *15*, 119–134.
49. Gao, X.; Xu, X.; Liu, C.; Zhao, J. Analysis of Ecological Community Planning and Design Strategies Based on the Concept of "Cradle to Cradle": A Case Study of PARK20/20 in Dutch. *Urban Stud.* **2019**, *26*, 85–91,107.
50. Kopnina, H. Green-washing or best case practices? Using circular economy and Cradle to Cradle case studies in business education. *J. Clean. Prod.* **2019**, *219*, 613–621.
51. Lin, C.-W.R.; Chen, M.-T.; Tseng, M.-L.; Chiu, A.S.F.; Ali, M.H. Profit Maximization for Waste Furniture Recycled in Taiwan Using Cradle-to-Cradle Production Programming. *Math. Probl. Eng.* **2020**, *2020*, 2948049. https://doi.org/10.1155/2020/2948049.
52. Hansen, E.G.; Schmitt, J.C. Orchestrating cradle-to-cradle innovation across the value chain: Overcoming barriers through innovation communities, collaboration mechanisms, and intermediation. *J. Ind. Ecol.* **2021**, *25*, 627–647. https://doi.org/10.1111/jiec.13081.
53. Bakker, C.; Wever, R.; Teoh, C.; De Clercq, S. Designing cradle-to-cradle products: A reality check. *Int. J. Sustain. Eng.* **2010**, *3*, 2–8.
54. Shah, J.J.; Kulkarni, S.V.; Vargas-Hernandez, N. Evaluation of idea generation methods for conceptual design: Effectiveness metrics and design of experiments. *J. Mech. Des.* **2000**, *122*, 377–384.
55. Demirova, S. Turning Knowledge into Innovation and Innovation into an Effective Product Concept. In Proceedings of the 2019 International Conference on Creative Business for Smart and Sustainable Growth (CREBUS), Sandanski, Bulgaria, 18–21 March 2019; pp. 1–4.
56. Liu, L.; Li, Y.; Xiong, Y.; Cavallucci, D. A new function-based patent knowledge retrieval tool for conceptual design of innovative products. *Comput. Ind.* **2020**, *115*, 103154.
57. McBeath, A.; Bager-Charleson, S. Introduction: Considering qualitative, quantitative and mixed methods research. In *Enjoying Research in Counselling and Psychotherapy*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 1–12.
58. García-Lara, S.; Chuck-Hernandez, C.; Serna-Saldivar, S.O. Development and structure of the corn kernel. *Corn* **2019**, 147–163.
59. Bjørn, A.; Hauschild, M.Z. Cradle to Cradle and LCA. *Life Cycle Assess. Theory Pract.* **2018**, 605–631.
60. Diller, G.P.; Haehling, S.V.; Anker, S.D.; Berlin, P.; Minutello, R.M.; Friedman, E.H.; Cleveland, E.; Guevara, M.M.; Ja, F.; Rd, C. Wosrld Health Organization. Obesity: Preventing and Managing the Global Epidemic. Available online: https://books.google.com.sg/books?hl=zh-CN&lr=&id=AvnqOsqv9doC&oi=fnd&pg=PA1&dq=World+health+organization.+obesity:+Preventing+and+managing+the+global+epidemic.&ots=6WL18nVW7P&sig=Cl-

aAqQ07rWEeL8TjFIatb4HrZI&redir_esc=y#v=onepage&q=World%20health%20organization.%20obesity%3A%20Preventing%20and%20managing%20the%20global%20epidemic.&f=false (accessed on 12 March 2023).
61. Strauss, R.S. Self-reported weight status and dieting in a cross-sectional sample of young adolescents: National Health and Nutrition Examination Survey III. *Arch. Pediatr. Adolesc. Med.* **1999**, *153*, 741–747.
62. Pesa, J. Psychosocial factors associated with dieting behaviors among female adolescents. *J. Sch. Health* **1999**, *69*, 196–201.
63. Välimaa, R.; Ojala, K.; Tynjälä, J.; Villberg, J.; Kannas, L. HBSC Study: Overweight, self-perceived body weight and dieting in 15-year-old adolescents in Europe, Israel and North America. *Suom Laak.* **2005**, *47*, 4843–4849.
64. Field, A.E.; Austin, S.; Taylor, C.; Malspeis, S.; Rosner, B.; Rockett, H.R.; Gillman, M.W.; Colditz, G.A. Relation between dieting and weight change among preadolescents and adolescents. *Pediatrics* **2003**, *112*, 900–906.
65. Salsabila, P.R.; Boonraksa, A.; Indriani, I.; Sakina, S.I.; Rahardyan, B. Cradle-to-Gate Life Cycle Assessment of Pineapple Leaf Fibres. In Proceedings of the ICON ARCCADE 2021: The 2nd International Conference on Art, Craft, Culture and Design (ICON-ARCCADE 2021), Bandung, Indonesia, 29–30 September 2021; pp. 130–139. Available online: https://www.atlantis-press.com/proceedings/icon-arccade-21/sessions/4278 (accessed on 12 March 2023).
66. Nguyen, C.T.X.; Bui, K.H.; Truong, B.Y.; Do, N.H.N.; Le, P.T.K. Nanocellulose from Pineapple Leaf and Its Applications towards High-value Engineering Materials. *Chem. Eng. Trans.* **2021**, *89*, 19–24.
67. Jawaid, M.; Asim, M.; Tahir, P.M.; Nasir, M. *Pineapple Leaf Fibers*; Springer: Berlin/Heidelberg, Germany, 2020.
68. Kambli, N.D.; Mageshwaran, V.; Patil, P.G.; Saxena, S.; Deshmukh, R.R. Synthesis and characterization of microcrystalline cellulose powder from corn husk fibres using bio-chemical route. *Cellulose* **2017**, *24*, 5355–5369.
69. Defloor, I.; Delcour, J.A. Impact of maltodextrins and antistaling enzymes on the differential scanning calorimetry staling endotherm of baked bread doughs. *J. Agric. Food Chem.* **1999**, *47*, 737–741.
70. Yildirim, E.; Taylor, A.; Spittler, T. Ameliorative effects of biological treatments on growth of squash plants under salt stress. *Sci. Hortic.* **2006**, *111*, 1–6.
71. Bocken, N.; Boons, F.; Baldassarre, B. Sustainable business model experimentation by understanding ecologies of business models. *J. Clean. Prod.* **2018**, *208*, 1498–1512.
72. Milovanovic, J.; Hu, M.; Shealy, T.; Gero, J. Characterization of concept generation for engineering design through temporal brain network analysis. *Des. Stud.* **2021**, *76*, 101044.
73. Jing, L.; Li, Z.; Peng, X.; Li, J.; Jiang, S. A relative equilibrium decision approach for concept design through fuzzy cooperative game theory. *J. Comput. Inf. Sci. Eng.* **2019**, *19*, 041001.
74. Lowhorn, G.L. Qualitative and Quantitative Research: How to Choose the Best Design. In Proceedings of the Academic Business World International Conference, Nashville, TN, USA, 28 May 2007; pp. 1–5.
75. Jacobs, H.R. *Mathematics: A human Endeavor*; Macmillan: New York, NY, USA, 1994.
76. Ayağ, Z. An integrated approach to concept evaluation in a new product development. *J. Intell. Manuf.* **2016**, *27*, 991–1005.
77. Wang, M.; Liu, S.; Wang, S.; Lai, K.K. A weighted product method for bidding strategies in multi-attribute auctions. *J. Syst. Sci. Complex.* **2010**, *23*, 194–208.
78. Jimenez, A.; Mateos, A.; Sabio, P. Dominance intensity measure within fuzzy weight oriented MAUT: An application. *Omega* **2013**, *41*, 397–405.