International Journal of Design & Nature and Ecodynamics
Vol. 19, No. 3, June, 2024, pp. 1069-1079
Journal homepage: http://iieta.org/journals/ijdne

Utilizing Spent Coffee Ground for Sustainable Ceramic Planters: A Material-Driven Innovation Approach

Devanny Gumulya*, Nayadipta Jayanasti, Susi Hartanto

School of Design, Pelita Harapan University, Tangerang, Banten 15811, Indonesia

Corresponding Author Email: devanny.gumulya@uph.edu

https://doi.org/10.18280/ijdne.190336

Received: 17 February 2024
Revised: 10 May 2024
Accepted: 15 May 2024
Available online: 25 June 2024

Keywords:
material innovation, Material Driven Design (MDD), design method, canvas, coffee waste

ABSTRACT

To address sustainability concerns, product designers have actively sought to repurpose waste into innovative materials, a phenomenon known as Material Driven Design. The global rise in coffee consumption, particularly in Indonesia, has led to an increase in coffee waste generation, contributing to environmental pollution and climate change. This study focuses on repurposing Spent Coffee Ground (SCG) as an additional material in ceramic production to mitigate environmental impact. Recognizing the need for a new design methodology to guide material-driven processes, this study combines qualitative literature review with a research-through-design approach. Drawing from existing studies on material innovation processes such as material-driven design and design-driven material innovation methodologies, the study proposes a comprehensive approach built upon these existing studies. This methodology, outlined in a canvas named Material Driven Innovation Canvas (MDIC), comprises seven building blocks: understanding the material, conceptualization, prototyping, setup, user testing, reflection, and iterations. The canvas is implemented in a design project to repurpose the SCG into a functional product. From a series of experiments, it was found that the strength of the clay and Spent Coffee Ground mixed material lies in its porosity, which is enhanced by incorporating 5% of fine coffee grounds. The coffee ground mixtures increase ceramic porosity and water absorption without compromising structural integrity. Hence, the proposed solution aims to develop two types of self-watering planters adaptable to various planting methods and species. To craft the ceramic planters, each planter needs a blend of 550 grams of clay and 5% Spent Coffee Ground (27.5 grams) is utilized. This mixture undergoes hand-throwing and carving to achieve the desired shape, followed by drying and firing at 900℃. Through the design project, it was determined that utilizing the MDIC adds simplicity, clear visual representation, holistic views, and facilitates collaboration. This research not only offers practical insights into leveraging Spent Coffee Ground (SCG) in ceramics but also showcases the effectiveness of the Material-Driven Innovation approach in transforming waste materials into innovative products.

1. INTRODUCTION

In recent decades, designers worldwide have been actively engaged in addressing sustainability issues by repurposing waste materials to create innovative advanced materials [1]. The focus is on transforming waste into promising materials that can offer distinct advantages in the market. This phenomenon is called Material Driven design coined by Karana et al. [2]. Material design plays a crucial role in this endeavor by identifying suitable applications for new materials, enhancing their functionalities based on technical properties, and leveraging the characteristics of waste materials for easy molding and manipulation to achieve desired sensorial attributes [3]. This approach not only seeks to give new life to waste but also aims to create materials that stand out from competitors, contributing to sustainability and market competitiveness.

One of waste that is abundance is Spent Coffee Ground (SCG). According to International Coffee Organization (ICO) data, the increase of coffee production in Indonesia each year is up to 2.5%-3%. Not only as a producer, but coffee consumption in Indonesia also continues to grow. In 2016-2021 alone coffee consumptions in Indonesia has increased by 8.22% per year and reached up to 300,000 tons of coffee consumed in the 2020/2021 period. The increase in coffee consumption is also supported by trends, habits and lifestyle surrounding drinking coffee. The high demand and interest in coffee resulted in a high amount of coffee waste. From 1 kg of coffee beans used, 1.88kg of Spent Coffee Ground (SCG) is produced [4]. This could lead to environmental problems because Spent Coffee Ground contains caffeine and tannins can become toxic to the surrounding environment and emit methane gas which pollutes the environment, that can eventually lead to global warming [5].

Spent Coffee Ground (SCG) have a lot of potential, one of which is the use of SCG as additional material in ceramic making. The concept of incorporating SCG into clay is not new, such attempts are made to increase the porosity in ceramic to produce different variety of products such as clay bricks [6], expanded clay ball [7], and bi-layered floor tiles (see Figure 1) [8]. Previous research indicates that incorporating organic materials into ceramics presents significant possibilities for creating diverse product variations. Incorporating coffee waste as an additive, the porosity of the ceramic can be precisely controlled to achieve the desired level, thus unlocking the potential for creating self-watering planters that facilitate efficient water absorption by the plants. Spent Coffee Ground could be the ideal organic material to enhance the porosity in ceramic since the grinding process itself creates a uniform size or coarseness.

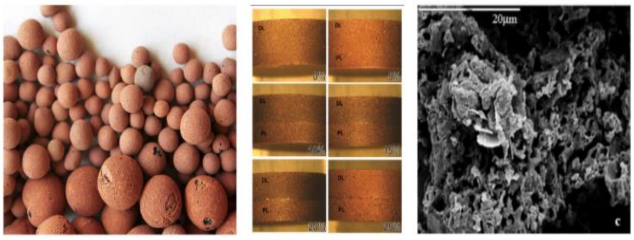


Figure 1. Leca or expanded clay ball (left) [6], bi-layered Floor (center) [7], brick clay samples (right) [5]

In a world where the number of products is constantly increasing, the use of innovative materials can help differentiate products from competitors, leading to distinctiveness in the market Jerz et al. [9]. To innovate with new materials and create innovative products, designers need a robust design method that can effectively guide them through the process. In design literature, two methods are commonly discussed for innovating with materials: material design-driven and design-driven material innovation methodologies.

This paper showcases a case study in which the theoretical frameworks from Karana et al. [2] and Ferrara and Lecce [10] are integrated to form a comprehensive design tool, which is then implemented in a practical sustainable design project.

This paper comprises five sections. The initial section examines material design-driven and design-driven material innovation methodologies, serving as the theoretical foundation for the research. The subsequent section outlines the development of a unified framework merging both MDD and DDMID, resulting in the creation of the Material-Driven Innovation Canvas (MDIC). Section three elucidates the application of the framework to a design project, where Spent Coffee Ground are repurposed into functional products. Following the case study, the strengths and limitations of the Canvas in educational and practical contexts are deliberated in the fourth section. Finally, the last section delves into discussions regarding future endeavors.

2. LITERATURE REVIEW

2.1 Material Driven Design (MDD)

MDD is a method to guide sustainable design process that is developed by Karana et al. [2]. It aims to design material experiences by considering not only the functional aptness of a material but also its ability to elicit meaningful user experiences. MDD involves understanding the engineering limitations and unique properties of the material, as well as its sensorial qualities and the emotions and perception it evokes in users.

MDD is a comprehensive sustainable design method because it focuses on the material as the main driver of the design process, considering its properties and potential experiences it can offer. Furthermore, MDD encourages tangible interaction with the material from the first encounter, allowing designers to explore and understand its unique qualities and limitations. Finally, MDD aims to create new product concepts that go beyond utilitarian assessment, by envisioning and materializing design intentions for a new material experience.

Material-Driven Design (MDD) encompasses three scenarios to guide designers in the creative process [2]. In Scenario 1, where a material is already developed, the focus lies on comprehending its technical properties, constraints, and opportunities. Designers delve into the material's sensorial qualities, attributing meaningful interpretations. Scenario 2 deals with semi-developed or composite materials, prompting designers to tinker with structures and discover optimal combinations based on material experience patterns. They manipulate sensorial qualities through surface treatments, forms, and manufacturing possibilities. In Scenario 3, when a material is not yet developed, designers initiate the process by creating material concepts informed by the outcomes from Step 3 and their experiences gained from Step 1. They subsequently test the performance of these concepts and evaluate the material's experiential qualities through mechanical tests, interviews, and focus group studies.

There are four main steps in how to implement MDD method [2]:

(1) Understanding the material: it involves gaining knowledge about the unique properties, sensorial qualities, and potential meanings of the material. It emphasizes the importance of hands-on exploration and practical exploration of materials to enhance the creative process and generate meaningful user experiences. There are two sub steps, the first one is technical characterization of the material, in which designers learn about the mechanical and technical properties of the material, as well as identifying the manufacturing processes that can be used to form the material. This can be achieved through accessing technical datasheets provided by material suppliers or online material databases. If the material is not fully developed, the designers can engage in hands-on experimentation with the material, such as cutting, bending, or combining it with other materials, to understand its inherent qualities, constraints, and opportunities. The second one is Experiential characterization of the material in Material Driven Design (MDD) involves understanding the material on four different experiential levels: sensorial, interpretive (meanings), affective (emotions), and performative (actions, performances). Sensorial qualities of a material refer to the specific characteristics that can be experienced through the senses, such as touch, sight, smell, taste, and sound. Interpretative is about how users perceive the material. User’s perception is shaped by associating it with other materials due to similar aesthetics. This association can influence how users perceive the material and can provide inspiration for design choices. The interpretative experiential level supports the sensorial experience because, to fully comprehend the material's sensorial qualities, it is essential to explore how people describe the material and the meanings it evokes. Affective is about how users' feeling when seeing the material. This can involve examining the emotions that the material elicits, such as surprise, love, hate, fear, relaxation, and so on. Lastly performative is what people do to the material naturally without given any instructions. This includes observing how users physically engage with the material, as well as any behavioral patterns that emerge. To gain the data designers should conduct FGD and ask several questions about the material in these four experientials levels.

(2) Creating a material experience vision: it involves formulating a clear and comprehensive vision statement expressing how a designer envisions the material's role in creating functional superiority and a unique user experience when incorporated into a product. Before crafting the vision, designers can conduct material benchmarking, studying and analyzing other materials and their applications to gain insights and inspiration for the material under consideration. This process helps designers understand potential application areas and experiential considerations emphasized in those domains. The vision statement should encompass the material's unique technical and experiential qualities, its potential positive impact in specific contexts, how people would interact with it, the unique contribution it would make, how it would be sensed and interpreted, what it would elicit from people, and what actions it would inspire. In conclusion, the material experience vision should summarize various findings and insights from the existing material that similar to the studied material to guide the designer's decisions throughout the design process.

(3) Manifesting Material Experience Patterns: it involves visualizing and categorizing datasets, including technical and experiential information about the studied material and related materials found during benchmarking studies. Through the analysis of these datasets, designers, utilizing their intuition and creativity, can identify patterns and classify them to formulate material experience patterns, using adjective words that represent the material, such as "modest" or "provocative." The keywords can be visualized through diagrams that represent the relationships between the user, product, and material in the context of material experiences. The user refers to the individual or group of individuals interacting with the product and engaging in the material experience. The product refers to the shape, function, and manufacturing process of the studied material. The material is the studied material containing technical and experiential qualities. The diagram visualizes how these three elements-user, product, and material-interact within a situational whole to create the overall material experience. Understanding these relationships enables designers to intentionally manipulate materials to create meaningful experiences for users.

(4) Designing material/product concepts: in this stage all the main findings are integrated into the design phase, where the designer creates material/product concepts based on the previous steps' outcomes. Designers can select concepts with the greatest potential by doing performance mechanical test on the studied material, this test is needed to assess whether the material is capable of fulfilling the required function or purpose. Designers should also evaluate the material's experiential qualities through insights gathered from focus group studies. In addition to technicalities and experiential qualities another important aspect to consider is their feasibility in terms of cost and production. By considering feasibility, designers can ensure that the ideas are practical and economically viable for commercialization.

2.2 Design driven material innovation methodology (DDMIM)

DDMIM is a systematic approach and strategic tool for designers based on integrating material design and product design, with a focus on understanding the qualities of materials in depth [8]. The success of material innovation depends on two important design outcomes: distinctiveness and user acceptance. Hence, the method emphasizes creating new values and meanings in products, with a strong emphasis on human pleasure and meeting consumer needs. It consists of seven steps: Data collection, Sensing, Sensemaking, Envisioning, Specifying, Setting up, and Placing [8].

(1) Data Collection: the first step in DDMIM is the process of gathering relevant information and data about the materials being studied. There are three main activities in this step. First, analyzing the material by gaining its technical data to understand its potential and characteristics. Second, benchmarking activities are conducted to position the material in the contemporary materials scenario and identify opportunities for its application in various sectors. Third, hands-on activities involve the exploration of the material through hands-on manipulation to understand its sensory potential and how it can influence the creative process.

(2) Sensing: this process involves understanding the users and the environment in which material innovation will take place. It includes gathering information and insights about users' needs, desires, and aptitudes in relation to their physical, physiological, ideological, and social well-being. This process helps designers gain a deeper understanding of the users and their context, which is essential for creating meaningful and impactful design solutions. In addition to information about users, the environment is also studied by gathering information about geographical, cultural, social, and economic factors, which helps define the cultural and behavioral characteristics of the project.

(3) Sensemaking: In this phase, designers generate concepts regarding the potential possibilities or desirable outcomes associated with the material. They create a conceptual framework or "material vision," establishing novel interpretations for the material and predicting upcoming trends. Sensemaking demands that designers employ their creativity to introduce innovation and present unique perspectives distinct from previous existing application of the material, outlining precise scenarios for the practical implementation of the envisioned concept. This stage holds significant importance in the formulation of design solutions that are both meaningful and influential, as it facilitates a comprehensive comprehension of the material and its prospective uses.

(4) Specifying: In this stage the concept defined in the previous stage is specified by choosing the most suitable product language which refers to the visual and functional characteristics of the product and using it as a specification for developing the first experimental prototype. The experimental prototype is a physical representation of the newly defined meaning and serves as a test version of the product. The purpose of developing the prototype is to evaluate its feasibility, functionality, and overall performance. The development of the experimental prototype is an essential step in the innovation design method as it allows for practical testing and validation of the design concept.

(5) Setting up: once the prototype is refined, the next step is the concept of "storytelling". Storytelling involves carefully designing a narrative that accompanies the new product and its defined new meaning. The purpose of storytelling is to amplify and relate the message of the new meaning to the potential customers. By creating a compelling story that aligns with the product language, the new product can be effectively introduced to the market. Additionally, the ability to effectively communicate the meaning of material or product innovation is crucial. Visual communication skills play a fundamental role in this process, as the message should be pleasant and easily understood by consumers. Aside from developing storytelling, another activity to do in this step is to evaluate the impact of the innovation by organizing a material experience session with potential users. This session allows for the evaluation of how the innovation resonates with users and its potential effects on society. By gathering feedback and insights from potential users, the product can be refined and improved before being introduced to the market.

(6) Placing: this step is to evaluate how innovation resonates with users and its potential effects on society. This means thinking about how the product will be made available to customers, whether it is through direct sales to businesses (Business to Business or B2B) or through sales to individual consumers (Business to Consumer or B2C). The role of design in this phase is to contribute to the implementation of the visual communication of the product. This involves creating visual elements such as packaging, branding, and marketing materials that effectively communicate the value and benefits of the product to the target audience. The design should align with the overall brand identity and messaging and help differentiate the product from competitors in the market.

On the other hand, with regards to recent studies incorporating organic waste in clay, according to Pranckevičienė and Pundienė [11], it was found that mixing clay with organic compound waste (OCW) modifies the pore structure of the clay and the ceramic product exhibits higher thermal conductivity. Another study of Silva et al. [12] found that organic waste like rice husks, banana leaves, and coffee waste can be used as porogenic agents in producing porous ceramics for applications like porous clay bricks and insulation materials. Another study by Zeeuw van der Laan [13] was a thesis published as study case in Karana et al.'s study [2] exploring the use of Spent Coffee Ground as fillers and fibers in bio-composites with an MDD approach and recommended the importance of understanding the experiential aspects of the material during the first stage of MDD. The experience of the Spent Coffee Ground is gained through sensorial engagement via its imperfect aesthetics. Hence, the study recommends prioritizing them over technical aspects in material design.

Unfortunately, recent research has not delved into tool development. To enhance user-friendliness, the integration of MDD and DDMID as design methods could be pivotal in guiding designers through the sustainable design process. In this study, a canvas is formulated, combining both approaches, serving as a valuable reference for designers engaged in sustainable design processes. Prior to constructing the canvas, the existing study about MDD hasn't develop a structured canvas or framework specifically tailored to guide designers through the MDD process [2, 14]. The development of a specialized canvas for MDD could address this gap, providing a systematically and user-friendly tool to facilitate the systematic integration of material properties, experiential qualities, and design objectives, thereby enhancing the efficacy and efficiency of material-driven design processes. Canvas is a great tool in the design process because it provides a visual platform for designers to conceptualize and organize their ideas. It allows them to see the overall structure of a design or project in a single view, facilitating better understanding and communication of complex concepts [15]. Therefore, this study poses the research question: How can we develop a canvas for the conceptualization of material-driven design?

3. METHOD

The present research employed a qualitative exploratory study design with research through design approach to investigate the topic of creating MDD canvas and apply it on design project, which has not been thoroughly investigated previously. Research through design (RtD) is an approach to research that integrates design practices and methodologies to address complex problems and generate new knowledge [16]. It involves using the design process itself as a means of inquiry, exploring and investigating research questions through the creation of tangible artifacts, prototypes, or interventions [17]. Unlike traditional research methods that primarily rely on analysis and observation, RtD emphasizes the act of designing as a way to understand, explore, and contribute to knowledge in various fields, including design, architecture, and human-computer interaction.

The research methodology involved a multi-step process. Initially, the study conducted a comprehensive literature review on Material Driven Design (MDD) and Design-Driven Material Innovation and Development (DDMID), elucidating the steps and considerations at each phase. Subsequently, the research constructed a framework that amalgamates both MDD and DDMID, creating a unified guide for the study. This framework was then applied to a design project, transforming Spent Coffee Ground into functional products, with the tangible output of the framework being the creation of planter prototypes. To create the ceramic planter, 550 grams of clay are required, mixed with 5% Spent Coffee Ground, equivalent to 27.5 grams. The mixture of clay and coffee grounds is then hand-thrown and carved to shape the form before being dried and fired at 900°C. The study did not include a control group because without the addition of Spent Coffee Ground to the clay, the ceramic lacks sufficient porosity to function as a self-watering ceramic planter.

Lastly, the study conducted user testing on the prototypes to assess user acceptance of the products, and researchers also reflected on and evaluated the effectiveness of the framework. This comprehensive approach aimed to identify areas for improvement in both the final product and the research methodology.

4. RESULT AND DISCUSSION

The study integrates both approaches, leveraging the strengths of Material Driven Design (MDD), which emphasizes building user experiences across four levels: sensorial, interpretative, affective, and performative, and combining it with the strengths of Design-Driven Material Innovation and Development (DDMID). The latter approach encompasses all steps, starting from collecting technical data about the material, engaging in hands-on exploration, conceptualizing the material into a product, prototyping, and concluding with the market launch of the material. The research output framework is named Material-Driven Innovation Canvas (MDIC).

The canvas is constructed, and each step is elaborated with prompt questions that will guide designers through the material innovation design process systematically (see Figure 2).

Scenario 1: an already developed material

Scenario 2: semi-developed or composite materials

Scenario 3: a not yet developed material

1. Understanding the material

1.1 Technical aspect

3 key main activities

Analyzing Material Characteristics:

- What are the technical data to understand the properties and capabilities of the material?
- What unique characteristics and potential can we uncover by comprehending the material's properties?

Benchmarking and Positioning:

How does the material c- ompare to contemporary materials in terms of its properties, characteristics, and performance?
- What potential opportunities exist for applying this material in various industries or contexts?

Hands-On Exploration:

- How can you explore with the material through touching, feeling, and manipulating it?
- What insights do you get about materials' texture, surface and other physical properties experienced by the skin and other sensory receptors in the body?

1.2 Experiential aspect

Understanding materials across four experiential levels: sensorial, interpretive, affective, and performative by conduction focus group discussion.

Level sensorial:
- How does the material feel when touched?
- What visual characteristics does the material exhibit? Does the material have any discernible odor?
- Is there a taste associated with the material?
- Does the material produce any sound when manipulated or interacted with?

Level interpretative:
- How do users relate the material to their prior experiences with similar materials?
- What aesthetic qualities of the material influence users' perceptions?
- Are there any cultural or societal associations that users attribute to the material?
- How do users' past encounters with similar materials impact their interpretation of the current material?
- What role do aesthetic preferences play in shaping users' perceptions of the material?

Level affective
- What emotions do users typically associate with the material?
- Can users identify any specific emotional responses triggered by interacting with the material?
- How do users' emotional reactions to the material influence their overall perception of it?
- Are there any cultural or personal factors that contribute to users' emotional responses to the material?
- How might designers leverage the material's emotional impact to enhance user experiences?

Level performative
- What are the typical ways users interact with the material without explicit instructions?
- Can you identify any recurring patterns in users' behavior when engaging with the material?
- How do users' interactions with the material vary across different contexts or environments?
- What insights can be gained from observing users' natural interactions with the material?
- How might designers optimize the material based on observed user behaviors and engagement patterns?

2. Conceptualization and Ideation

- How can user insights be integrated into innovative ideas for material utilization? What visual attributes correspond with the desired user experience?

- How might the unique characteristics of the material inspire new design concepts that prioritize user experience while utilizing the material effectively?

- In what ways can designers ensure that the proposed designs effectively leverage the material's properties?

3. Prototyping

- Develop prototypes that reflect the envisioned design concepts, while ensuring that prototypes effectively balance functionality, aesthetics, and usability

- Iterate on prototypes and address any identified shortcomings or areas for improvement

4. Setting up

- What specific narrative should be crafted to accompany the new product and its defined new meaning?

- Ensure that the narrative aligns with the product language

- Generate visual content that effectively conveys the significance of material or product innovation to consumers through communication.

5. User testing

- What methods would you employ to conduct user testing and gather feedback on prototype performance and user experience?

- How would you incorporate user feedback into iterative design improvements to enhance the product?

6. Reflection and Iteration:

- What strategies can be implemented to refine and improve the product based on feedback and insights gathered from potential users?

- In what ways can the feedback obtained from the material experience session inform the refinement and improvement process before introducing the product to the market?

Figure 2. The material driven innovation canvas

Scenario 2: semi-developed or composite materials
Combining spent coffee grounds (SCG) waste with clay

1. Understanding the material

1.1 Technical aspect
Analyzing Material Characteristics:
1.1.1 Finding the best mixture ratios
The process

The coffee ground is weigh — The clay is weigh — Coffee grounds are hydrated with a 1:1 water ratio to prevent them from absorbing water from the clay — Coffee grounds are periodically added to facilitate mixing and ensure uniform results.

Spent coffee ground percentage	Material Strength	Technique Variations	Porosity	Amount of waste used	Total
5% coarse	5	3	1	5	14
5% fine	6	6	2	6	20
5% coarse and 5% fine (1:1)	4	5	3	2	14
5% fine and 10 % coarse (2:1)	3	4	4	3	14
10% fine	2	2	6	2	12
15% fine	1	1	5	1	8

Key findings to further explore: 5% Fine coffee is the best spent coffee ground percentage to be mixed with clay

1.1.2 Understand the properties and capabilities of the material

After the mixed material gone under bisque firing it is founded that incorporating coffee grounds into ceramics introduces pores into the ceramic structure. These pores enhance the ceramic's ability to absorb and distribute water across its surface. Additionally, the inclusion of coffee grounds enables the ceramics to withstand higher firing temperatures, ensuring good strength while preserving high porosity properties.

Key findings to further explore: The coffee grounds increase porosity on the clay

1.1.3 Engage in hands-on exploration to understand the material's characteristics through touch, feel, and manipulation.

Key findings regarding coffee grounds in clay mixtures:
1. Fine coffee grounds are easier to shape compared to coarse ones.
2. Shaping thin walls with coffee-infused clay poses challenges.
3. Coffee grounds texture complicates pottery wheel use.
4. A 7.5% coffee grounds mixture with 1:1 coarse to fine ratio is suitable for wheel throwing but requires slower shaping.
5. Trimming and carving are slower with coffee grounds, and drying time increases with higher coffee grounds percentages.
6. The Kurinuki technique is favored for its simplicity.
7. 5% coffee grounds produce a smoother texture, while 10% results in a rougher texture.
8. Forming with a 15% coffee grounds mixture shows no significant texture differences.
9. Carving is easier in semi-dry or leather-hard clay with 15% coffee grounds, facilitating the process.

Ceramic Technique	Efficiency	Success	Aesthetic	Texture	Total
Pinching	1	1	1	1	4
Kurinuki	2	3	2	2	9
Wheel throwing and carving	3	2	3	3	13

Key findings to further explore: Wheel throwing portrays the coffee coarse better than the kurinuki technique. Trimming and carving are slower with coffee grounds, and drying time increases with higher percentages of coffee grounds.

5. Setting Up

The narrative highlights the journey of coffee waste transforming into a functional and eco-friendly material. Visual content features earthy tones to align with sustainability principles. It focuses on describing the unique characteristics of the material and provides step-by-step instructions for using the planter effectively.

1.2 Experiential Aspect

Four samples of clay and coffee grounds mixtures are tested by five users to gather insights about their experiences with the material.

Sensorial Level
- Users feel a slight grainy or textured sensation when touching the clay and coffee grounds mixture.
- Visual characteristics include speckles or flecks within the clay, indicating the presence of coffee grounds.

Interpretative Level
- Users associate the mixture with familiar pottery or ceramic materials, appreciating its aesthetic qualities like its speckled appearance and unique texture.
- Some users connect the mixture with concepts of sustainability or organic materials, influencing their perception of its visual appeal.
- Aesthetic preferences strongly influence users' perceptions, driven by personal taste and artistic sensibilities.

Emotional Level
- Users experience feelings of curiosity, intrigue, and novelty when interacting with the material due to its unique texture and appearance.
- They feel a sense of connection to nature or eco-friendliness because of its organic composition.
- Cultural backgrounds and personal experiences significantly influence users' emotional responses, with some valuing its sustainability aspect more than others.

Performative Level
- Users typically interact with the clay and coffee grounds mixture by touching it, exploring its texture through tactile sensations, without explicit instructions.

Key findings to further explore: Users associate the material's texture with organic and sustainable attributes.

3. Ideation and Conceptualization

3.1 Ideation
Based on hands-on exploration and technical experiments, it was determined that the optimal percentage of coffee grounds in the mixture is 5% fine coffee grounds. This concentration demonstrated superior strength, technique variation, porosity & absorbency. Considering user experience aspects, users perceive a slightly grainy or textured feel due to the presence of coffee grounds, associating the material with organic and sustainable attributes. Hence, the keywords for exploration are "natural" and "rustic," as rustic objects often feature rich textures.

3.2 Conceptualization
The porous nature of the material inspired the concept of self-watering planters, allowing plants to absorb water through ceramic pores. Self-watering planters allow plants to absorb water according to their needs through the ceramic pores. With minimal upkeep required, the planters are targeted towards modern urban dwellers who desire the freshness of indoor plants despite busy city lives. The planters can be used to propagate plants through methods like cuttings or to grow seeds such as microgreens.

6. User testing

The prototypes underwent five user tests with the intended target market to gain a better understanding of the product experience. The product was evaluated based on eight design factors, rated on a scale of 1 to 5 as outlined below

Design Factor	1	2	3	4	5	Score
Design Concept Idea	5	5	4	4	5	4,6
Innovation	4	5	5	4	4	4,4
Final Design	4	4	5	4	4	4,2
Ease of Use Kopi Groove Planter	5	4	3	4	4	4
Ease of Use Kopi Cavity Planter	4	4	5	4	3	4
Product Functionality	5	4	4	4	5	4,4
Product Size	4	5	4	4	5	4,4
Product Price	5	5	3	4	4	4,2

Based on the user review results, most respondents expressed interest in the product, finding it innovative, functional, and highly decorative. While both planters were deemed easy to use, some users noted that the space between the walls in the Kopi Cavity Planter was too narrow, limiting plant choices and complicating planting. To address this, adjusting the gaps between the walls to accommodate various plant sizes was suggested. Additionally, users found the finger groove too small and its placement at the bottom made the planter unstable when moved. However, the overall size of both planters was considered appropriate. Both the Kopi Cavity and Groove Planters received positive feedback from users, with an average score of 4.2.

3.3 Growing plants on the planter studies with Horticulturist

Philodendron — Microgreen Sweet Pea

Chia Seed — Microgreen Spinach

From the four plant studies conducted with a horticulturist, several conclusions can be made:
1. Ornamental plants like philodendron and similar aroids are ideal for self-watering planters due to their easy growth with just planter media and water.
2. These plants have taproots that attach and climb well.
3. Moss media is not necessary for aroids, enabling planting with just a planter and water.
4. Microgreen planting requires media to bind seeds, limiting the types of seeds usable in self-watering planters.
5. Seeds larger than 2mm struggle to mix well with cocopeat soil media and tend to fall during planting.
6. Ideal microgreen seeds for self-watering planters include spinach, carrots, sesame, basil, among others.

The authors can conclude that from the plant studies conducted, the planter design can be divided into two designs to accommodate the types or species of plants that can be used, with the specifications/ features as follows:

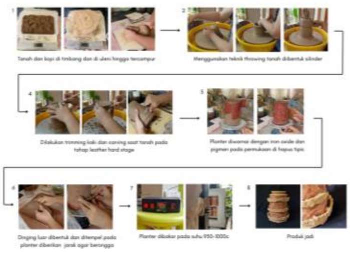
Planter design criteria for ornamental plants: Having a cavity to place plants with a cavity size of approximately 1cm. Rough textured on the body of the ceramic overall.

Planter design criteria for microgreens:
Having a recess/hollow for planting space (min 0.5 cm). Rough textured on the plant hollow. Cone-shaped (bottom widens) to prevent planting media from falling easily.

Both planters need to have a finger groove to facilitate product movement or handling.

4. Prototyping

4.1 The Process



4.2 Final Prototypes
The product's name is Kopi Planter, the word kopi means coffee in Indonesia. Kopi Planter has two variety of products which are Kopi Groove Planter specifically for planting microgreens and Kopi Cavity Planter that are ideal for ornamental plants like philodendron, aroids, begonia, ferns, hoya and other small plants.

Microgreen Planter	Houseplants Planter
Have double walls/pockets feature (approximately 1cm in width) to put plants	Have grooves with minimal 5mm in depth for planting
Rough texture throughout the planter	Rough texture inside the grooves
Double walls/pockets made into several sections/levels	Have a cone shape with wider base at the bottom
Made with clay and 5% fine coffee grounds with throwing and carving technique	
Complete with finger groove, lid and water dish	

Figure 3. The Spent Coffee Ground project material driven innovation canvas

The canvas is implemented in a design project aimed at recycling coffee waste into functional products. The Spent Coffee Ground (SCG) project falls under scenario 2, wherein the coffee waste needs to be combined with other materials to enhance its strength and durability. Hence the study is an experimental study to create a composite material coffee coarse waste combined with clay (see Figure 3). The process of MDIC is summarized below.

4.1 Understanding the material: Technical aspects

From series of experiments, it is found that the optimal percentage of Spent Coffee Ground in the mixture is 5% fine coffee grounds. This concentration demonstrated superior strength, technique variation, porosity & absorbency that can be good for plant growth.

To form the material, the Kurinuki ceramic hand building technique stands out for its simplicity and easiness. Carving wet clay yields a rough surface, whereas leather-hard clay allows for neater details. Additionally, the material can be shaped through hand throwing and carving. The study determined that hand throwing and carving are the optimal methods for creating planters due to their efficiency, higher success rate, and capacity for extensive form explorations. Texture varies with coffee ground concentration, with 5% mixture yielding smoother results and 10% creating rougher textures. Trimming and carving are slower with coffee grounds, and drying time increases with higher coffee grounds percentages.

4.2 Understanding the material: Experiential aspects

Considering user experience aspects, it is found that users perceive a slightly grainy or textured feel due to the presence of coffee grounds, associating the material with organic and sustainable attributes. Based on the feedback, we agree to prioritize the grainy and textured experiential aspects, aligning with Zeeuw van der Laan [13], who asserts that such qualities can enhance the user experience.

4.3 Conceptualization and ideation

Based on hands-on exploration and technical experiments, it was found that the optimal ratio of coffee grounds in the mixture is 5% fine coffee grounds, offering superior strength, technique variation, and porosity. Users perceive a slightly grainy texture due to the Spent Coffee Ground, associating the material with organic and sustainable attributes, prompting exploration into "natural" and "rustic" elements. The porous nature of the material inspired the concept of self-watering planters, allowing plants to absorb water through ceramic pores, catering to modern urban dwellers seeking indoor plant freshness with minimal maintenance.

4.4 Prototype

The concept of the planters is prototyped into tangible objects using the CCG and clay composite material. To validate the functionality of the composite material for planters, designers collaborated with a horticulturist to cultivate plants on the prototypes. The study revealed that while the composite material is effective as a planter, two distinct designs are necessary to accommodate different plant types. To nurture ornamental plants, the planter should include a cavity with a depth of approximately 1cm and a rough texture across the ceramic body (see Figure 4). For microgreens, the planter should feature a recess or hollow for planting space (minimum 0.5cm depth) with a rough texture inside the hollow (see Figure 5). Additionally, the planter should have a cone-shaped structure (widening at the bottom) to prevent planting media from easily falling out.

Based on previous findings, the waste is transformed into two types of planters named “Kopi”, the word kopi means coffee in Indonesia. Kopi Planter has two varieties of products which are Kopi Groove Planter specifically for planting microgreens and moss and Kopi Cavity Planter that are ideal for household plants like aroids, begonia, ferns, hoya and other small plants.

Figure 4. Kopi planter for ornamental plants

Figure 5. Kopi planter for micro green

4.5 Setting up

After creating the prototype, the subsequent step involves meticulously crafting a narrative to accompany the new product and its defined significance. This narrative underscores the process of transforming coffee waste into a functional and eco-friendly ceramic planter. Visual content adopts earthy tones to resonate with sustainability principles and emphasizes the distinctive attributes of the material. Additionally, it offers clear instructions for effectively utilizing the planter (see Figures 6 and 7).

Figure 6. Kopi cavity planter for ornamental plants instruction guide

Figure 7. Kopi groove planter for micro green instruction guide

5. USER TESTING

Based on the user review results, most respondents expressed interest in the product, finding it innovative, functional, and highly decorative. Both the Kopi Cavity and Groove Planters received positive feedback from users in six different aspects: Sustainable Design Concept Idea, Innovativeness, the craftsmanship quality of the Final Design, Ease of Use of the Kopi Groove Planter, Ease of Use of the Kopi Cavity Planter, Product Usability, Product Size, and Product Price, receiving an average score of 4.2 out of 5, with the highest score of 4.6 in the sustainable design concept idea.

6. REFLECTIONS AND ITERATIONS

Based on the feedback received, several improvements can be made to enhance the design of the planters. Firstly, the wall gaps of the Kopi Cavity Planter should vary in size to accommodate various ornamental plants. Future research should conduct usability testing with different plant species to determine the optimal gap size for versatile planting options. Secondly, the space at the bottom of both planter designs needs to be redesigned to improve grip and stability when moving the planter.

From implementing the MDIC canvas on design project, several findings can be made.

6.1 Simplicity

The canvas distills complex material innovation process into seven building blocks in a single visual format, making it easy to understand and communicate various aspects of the material innovation process from the first stage which is understanding the material both technically and the user experience factors to the last stage which is reflection and iteration.

6.2 Clear visual representation

The canvas offers a visual representation of the material innovation process, allowing designers to quickly grasp the interrelationships between different building blocks of material innovation process and identify areas for improvement. The prompts provided for each building block guide designers on the actions to take at each stage of the material innovation process. At the end of each step, the canvas requires designers to document the key findings for further exploration. By recording the findings at the end, it ensures that they are integrated into the next stage of the process. The material innovation process as explained by Ferrara and Lecce [10] as a continuous process, with each preceding step forming the basis for the subsequent ones. Therefore, by offering a clear visual representation, the canvas ensures that the insights gained from previous steps are duly incorporated into the following ones.

6.3 Holistic view

It provides a comprehensive view of the material innovation process, encompassing critical aspects such as technical considerations and user experience factors. Apart from bridging the technical and user experience dimensions, the canvas also establishes a link between the customer's viewpoint and the designer's perspective, facilitating the development of practical product innovations that can be promptly implemented. Using a matrix to evaluate the best outcomes increases objectivity in determining which results should be considered further. The study is consistent with Karana et al. [2], who suggested that in the material design process, designers should gather insights about the material from various angles, not solely through direct benchmarking or experimentation but also by considering user experiences. Therefore, by aligning all the building blocks of the material innovation process, the canvas ensures that all factors are considered, enabling designers to envision the innovation process holistically.

6.4 Facilitates collaboration

The canvas serves as a collaborative tool, enabling designers to brainstorm, analyze, and align various aspects of the material innovation process with other stakeholders like users and engineers. During the Spent Coffee Ground project, the researchers collaborated with horticulturist to discuss the type of plants suitable for the plants. The complexity of materials' natural behavior necessitates interdisciplinary collaboration involving engineering design and materials experts. This interdisciplinary approach enhances the innovation and efficiency of the process [18]. The canvas serves as a communication tool, providing a quick snapshot of the material innovation process and enabling stakeholders to grasp the big picture efficiently. This can prove useful in addressing the specific challenges and opportunities associated with innovative materials. As a result, the canvas fosters valuable learning experiences for both researchers and stakeholders, while also enhancing engagement among them.

In this paper, we demonstrated the effectiveness of the MDIC approach in a specific project centered on 'utilizing waste coffee grounds in design'. By leveraging the canvas, this research contributes to the expansion of existing research on blending SCG with clay. While the composite material has been previously applied as clay bricks [6], expanded clay balls [7], and bi-layered floor tiles [8], this study introduces a new application by creating functional self-watering ceramic planters from the mixed material.

The MDIC approach will be later elaborated in specific courses focusing on 'sustainable design' offered by the Faculty of Design at Pelita Harapan University. Our long goal is to showcase the applicability of the method across various projects falling under the three distinct scenarios outlined in this paper: designing with a familiar material, a completely new material, and a partially developed new material. In our future research, we aim to explore two additional scenarios that were not covered in the project outlined in this paper. Like any tool, as we implement it in more projects, there may be areas that require refinement. Therefore, future research can continuously enhance and adjust the canvas based on feedback and practical application to address any weaknesses that may arise.

In addition to the canvas, the study also has an environmental impact by recycling 5kg of Spent Coffee Ground for both the experiments and prototypes. The lifecycle analysis on the planters reveals that they are made from stoneware clay, a natural material. Spent Coffee Ground is generally considered biodegradable, breaking down relatively quickly in natural environments and contributing to soil health as they decompose. A study by Lachman et al. [19] found that SCGs can be neutralized to promote plant growth while maintaining anti-herbivore properties after partial decomposition of up to 8 months. Unfortunately, when the SCGs are decomposing it involves the action of microorganisms converting the organic matter into simpler compounds, such as biogas, which primarily consists of methane and carbon dioxide [20]. The potential emission of methane gas from the increased use of Spent Coffee Ground (SCG) poses another dilemma that can limit the study. If SCGs are not utilized, they will decompose and emit methane gas. However, if they are recycled by incorporating them into clay, they can be transformed into new materials, mitigating environmental impact. On the other hand, if ceramic planters are simply discarded, the environmental problem of methane emission persists.

On the economic side of this project, we calculated a total cost of $1,059.41, in addition there is a tool investment of $1,626.02, with the highest cost attributed to the ceramic kiln investment. If we divide the material cost by 10 and the tool investment by 3000 uses, we find that the cost of goods for the planters is approximately $6.1. If sold, it's advisable to triple the cost to cover additional expenses such as marketing and packaging. This would set the price at around $18. This price is reasonable compared to regular ceramic planters, which typically range from $16 to $31 in Indonesia. Hence, we really do belief that this project can be viable as a business in the future.

7. CONCLUSION

In conclusion, the study has successfully created a canvas that combines the strengths of existing methodologies to develop a more comprehensive tool for systematically guiding designers through the material innovation process. The canvas distills the complexities of material innovation into seven easily understandable building blocks: understanding the material, conceptualization, prototyping, setup, user testing, reflection, and iterations.

The implementation of the MDI canvas into the design project, focused on crafting self-watering ceramic planters using a blend of coffee coarse grounds and clay, has offered valuable insights into the canvas's efficacy in structuring the material innovation process. The canvas simplifies the complex nature of the material innovation process, guiding designers from the initial understanding of the material to the reflection and iteration stages. Its clear visual representation allows designers to comprehend the relationships between different stages and integrate insights gained from previous steps into subsequent ones, ensuring a continuous and iterative process. Furthermore, the canvas offers a holistic view by considering both technical aspects and user experience factors, aligning with the need for comprehensive understanding during material innovation. Additionally, it serves as a collaborative tool, fostering interdisciplinary collaboration among designers, users, and engineers, thereby enhancing innovation and efficiency in the material innovation process.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to the Institute of Research and Community Services at Pelita Harapan University for facilitating this research project. This paper is one of several publications resulting from the research agreement P-59-SOD/I/2023.

REFERENCES

[1] Gumulya, D. Gunawan, C. (2023). Designing colorful sustainable toys for babies: A sustainable design approach. International Journal of Design & Nature and Ecodynamics, 18(3): 593-603. https://doi.org/10.18280/ijdne.180311

[2] Karana, E., Barati, B., Rognoli, V., Zeeuw Van Der Laan, A. (2015). Material driven design (MDD): A method to design for material experiences. International Journal of Design, 9(2): 35-54.

[3] Bois, E.D., Veelaert, L., Tormans, E., Moons, I. (2021). How should plastic recyclates look like to be perceived as sustainable: A first exploration. In Proceedings of the Design Society. https://doi.org/10.1017/pds.2021.438

[4] Cameron, A., O'Malley, S. (2016). Coffee ground recovery program summary report. Planet Ark. https://static1.squarespace.com/static/5385613ee4b0883f7108f96f/t/5ccbc0f0971a1850c2c59049/1556857129706/Coffe+Ground+Recovery+Program+Report+2019_Planet+Ark.pdf, accessed on Jun. 3, 2024.

[5] Fernandes, A.S., Mello, F.V.C., Thode Filho, S., Carpes, R.M., Honório, J.G., Marques, M.R.C., Felzenszwalb, I., Ferraz, E.R.A. (2017). Impacts of discarded coffee waste on human and environmental health. Ecotoxicology and Environmental Safety, 141: 30-36. https://doi.org/10.1016/j.ecoenv.2017.03.011.

[6] Eliche-Quesada, D., Pérez-Villarejo, L., Iglesias-Godino, F.J., Martínez-García, C., Corpas-Iglesias, F.A. (2011). Incorporation of coffee grounds into clay brick production. Advances in Applied Ceramics, 110(4): 225-232. https://doi.org/10.1179/1743676111Y.0000000006

[7] Maryam, M.S., Faryuni, I.D., Nurhanisa, M., Maryani, E. (2020). Sintesis dan analisis sifat fisis hidroton berbasis ball clay dan cocopeat sebagai media tanam hidroponik. Jurnal Fisika Flux: Jurnal Ilmiah Fisika FMIPA Universitas Lambung Mangkurat, 17(1): 9-13. https://doi.org/10.20527/flux.v17i1.5862

[8] Busch, P.F., Holanda, J.N.F. (2022). Potential use of coffee grounds waste to produce dense/porous bi-layered red floor tiles. Open Ceramics, 9: 100204. https://doi.org/10.1016/j.oceram.2021.100204

[9] Jerz, J., Wilfinger, B., Hasenauer, R., Filo, P., Lazarová, M., Toroud, T. (2013). Market entry of innovative products using knowledge acquired by materials science and engineering. In INTED2013 Proceedings, Valencia, Spain, pp. 1378-1386.

[10] Ferrara, M., Lecce, C. (2016). The design-driven material innovation methodology. In Proceeding of IFDP16-Systems & Design Beyond Processes and Thinking, Spain, pp. 431-448. https://doi.org/10.4995/IFDP.2016.3243

[11] Pranckevičienė, J., Pundienė, I. (2022). Use of magnesium silicate contaminated with organic compounds in ceramic materials as a pore modifier. Materials, 15(24): 8833. https://doi.org/10.3390/ma15248833

[12] Silva, K.R., Menezes, R.R., Campos, L.F.A., Santana, L.N.L. (2022). A review on the production of porous ceramics using organic and inorganic industrial waste. Cerâmica, 68: 270-284. https://doi.org/10.1590/0366-69132022683873309

[13] Zeeuw van der Laan, A.C.M. (2013). Characterisation of waste coffee grounds as a design material: A case study of material driven design. Tu Delft.

[14] Pedgley, O., Rognoli, V., Karana, E. (Eds.). (2021). Materials experience 2: Expanding territories of materials and design. Butterworth-Heinemann.

[15] Pardalis, G., Mahapatra, K., Mainali, B. (2022). A business model canvas framework for sustainable one-stop-shops. In IOP Conference Series: Earth and Environmental Science. IOP Publishing, 1085(1): 012048. https://doi.org/10.1088/1755-1315/1085/1/012048

[16] Zimmerman, J., Forlizzi, J. (2014). Research through design in HCI. In Ways of Knowing in HCI. New York, NY: Springer New York, pp. 167-189. https://doi.org/10.1007/978-1-4939-0378-8_8

[17] Stappers, P.J., Giaccardi, E. (2018). Research through design. In: The Encyclopedia of Human-Computer Interaction, 2nd Ed.

[18] Hanahara, S. (2021). How collaboration between industrial designers and other members related to

product development affect innovation and efficiency. Annals of Business Administrative Science, 20(2): 47-62. https://doi.org/10.7880/abas.0210127a

[19] Lachman, J., Lisý, M., Baláš, M., Matúš, M., Lisá, H., Milčák, P. (2022). Spent Coffee Grounds and wood co-firing: Fuel preparation, properties, thermal decomposition, and emissions. Renewable Energy, 193: 464-474. https://doi.org/10.1016/j.renene.2022.05.003

[20] Kueh, A.B.H. (2021). Spent ground coffee–Awaking the sustainability prospects. Environmental and Toxicology Management, 1(1): 1-6. https://doi.org/10.33086/etm.v1i1.2016