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E-B Environment - Behaviour Proceedings Journal

AicE-Bs2024Bandung

e-IPH e-International Publishing House Ltd., United Kingdom

https://www.amerabra.org/

12th Asia-Pacific International Conference on Environment-Behaviour Studies
Savoy Homann Bidakara Hotel, Bandung, Indonesia, 04-05 Oct 2024

Role of Design Thinking in Socio-Technical Activity for Product Manufacturing

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Abstract
Human interaction intensively impacts design in product manufacturing through design thinking, interpreted product recognition and perceptual product experience (PPE). While the dominant digitalization and artificial intelligence in generative design present significant opportunities for innovation and optimization, there is a gap in adopting holistic, human-centered approaches. Despite numerous advancements, these methods, including design thinking, are not widely practiced, and there is limited discussion on effective design methodologies. This research aims to address this issue by investigating the influence of human interaction on design processes, integrating socio-technical principles, and analyzing how product form affects user perception and recognition.

Keywords: Design thinking; Socio-Technical Activity; Product Manufacturing

DOI: https://doi.org/10.21834/e-bpj.v9i30.6201

1.0 Introduction

As technological advancements continue to reshape the manufacturing industry, design thinking has become an increasingly vital methodology across various design dimensions, including product recognition and perceptual product experience (PPE). These factors are critical for fostering user-centered product development and require a deep understanding of the variables driving these interactions (Sun, 2022). Design thinking, broadly recognized as an analytical process, is central to design and product development activities, providing a critical framework for evaluating the relevance and impact of design findings in theoretical and practical contexts (Saroogi, 2019). Digitalization and artificial intelligence, particularly in generative design, have further revolutionized design development by introducing innovative approaches that enhance functionality and sustainability (Mourtzis, 2022). However, design thinking remains underutilized despite its importance, especially in the social sciences, where many products and services are developed without adhering to fundamental design principles. This underutilization is partly due to a lack of comprehensive understanding of designers' practical challenges in implementing this approach (Linder & Nilsson, 2022; Tromp & Vial, 2023). Although technological advancements offer significant potential, integrating socio-technical principles into design processes is still limited. Understanding how a product's visual and physical characteristics influence user perception and experience is crucial for effective design. Integrating socio-technical principles into design practices offers a framework for creating user-centered solutions that address technical and social factors. However,

DOI: https://doi.org/10.21834/e-bpj.v9i30.6201

challenges in design practice and the lack of comprehensive methodologies continue to limit the full potential of these approaches. This research seeks to bridge this gap by exploring how human interaction influences design thinking, product recognition, and PPE. By examining the role of socio-technical principles and how product form affects user perception, this study proposes a more holistic framework for product development that enhances the effectiveness and responsiveness of design practices in line with the evolving demands of technology and user needs.

2.0 Literature Review

Human interaction is crucial in product design, greatly impacting how products are created and perceived (Wang, 2020). User interaction involves how people engage with a product—how they see it, use it, and respond to it. This interaction is essential for interpreting product recognition, where users identify and understand a product based on their experiences. In product manufacturing, human interaction shapes design through socio-technical activities, which combine social and technical aspects in the design process. These activities, including design thinking, product recognition, and perceptual product experience (PPE), are essential for creating user-centered products that are recognizable, meaningful, and satisfying (Vaidya & Kalita, 2021).

According to Vaidya (2021), product recognition is closely tied to how users perceive and interact with a product, shaping their overall impression and engagement. Furthermore, perceptual product experience encompasses users' subjective, emotional, and evaluative responses to a product, which is fundamental in delivering a meaningful and memorable user experience (Liu & Cui, 2020). As the interface between humans and products becomes increasingly significant, understanding how a product's visual and characteristic attributes convey specific meanings, emotions, and connections is essential for creating compelling, engaging, and user-centered designs. PPE refers to the immediate, sensory-based interactions and impressions users have when they encounter a product. These sensory interactions form the first layer of user experience and significantly influence the user's initial perception of the product. (see Fig.1 below).

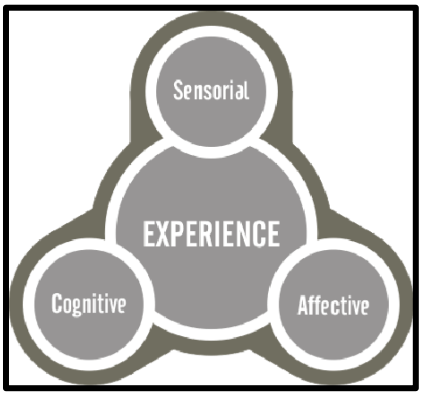

Fig. 1. The Core Mode of Perceptual Product Experience (PPE).
(Source: Warell, 2008)

Figure 1 illustrates the Perceptual Product Experience (PPE) framework, which includes three key sensory, cognitive, and emotional elements. The sensory element focuses on how users engage with a product through senses like sight and touch. The cognitive element involves understanding how the product works and its usability, while the emotional element looks at the feelings the product evokes. According to Warell (2008), this framework emphasizes that a successful product should be functional, visually appealing, easy to understand, and emotionally engaging. By considering these aspects, designers can create products that work well and connect with users on a deeper level. Sensory interactions are crucial in forming users' initial impressions, and each user may perceive a product differently based on its features (Wedowati et al., 2020; Warell, 2008). By focusing on user needs and experiences, designers can create functional and emotionally resonant products in line with socio-technical principles (Liedtka, 2020).

The role of human interaction is paramount in design thinking, as it involves engaging directly with users to gain insights into their needs, desires, and challenges. This iterative process of understanding, ideation, prototyping, and testing ensures that the final product or solution is well-aligned with user expectations, serving as a structured framework for creative problem-solving in design activities (Verma, 2023). It is a sequence of interrelated actions that foster innovation in addressing socio-technical challenges in manufacturing. Although challenging to define precisely, design thinking generally refers to cognitive processes that generate innovative solutions for products and services. Service innovation, driven by technology and systems approaches, significantly impacts economic policy, design, management, and technology studies (Fung et al., 2023)

In 2009, design activities evolved into a critical mechanism for product and service development innovation, commonly called design thinking. The concept has gained significant popularity, becoming a widely recognized approach for designers' thinking and working methods (Liedtka & Ogilvie, 2011). Design thinking integrates various perspectives, approaches, roles, activities, and methods to form a cohesive system model (Vaidyanathan & Henningsson, 2023). Research indicates that design thinking involves developing a structured system, with various frameworks proposed by researchers based on their findings and perspectives. One example is the

Stanford Design Thinking process by Hasso-Plattner (2012), which includes five phases: empathy, design, creativity, prototype, and test. (see Fig.2 below).

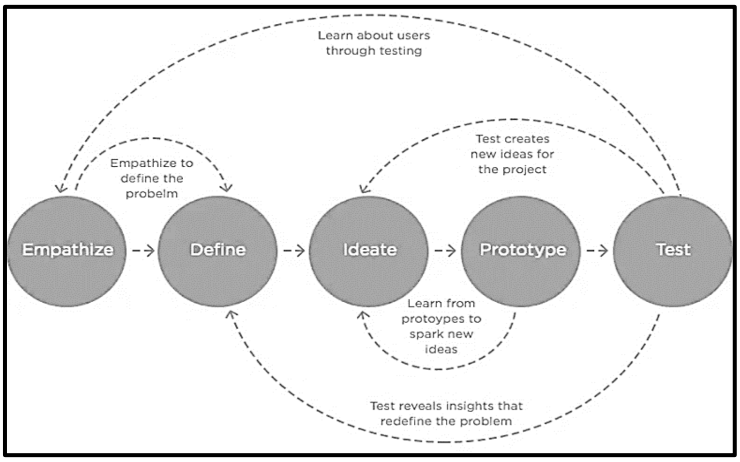

Fig. 2. The Stanford Design Thinking Process.
(Source: Li, 2019)

Figure 2 indicates that the Standford Design Thinking process is structured based on five phases and offers a systematic design thinking approach commonly visualized as problem-solving that prioritizes user needs and innovative solutions (Taimur, 2023). It consists of empathizing with users, often involving research, observation, and engaging with people to gather their experiences and perspectives. This model is highly structured and well-suited for product development, which requires a deep connection with user experience and a strong focus on creative problem-solving. This winning combination makes it one of the most valuable problem-solving methods today (https://makeiterate.com/the-stanford-design-thinking-process/), and it can lead to more effective, user-friendly and innovative outcomes in various fields, from product design to service delivery and problem-solving in diverse areas.

Moreover, Sample 2, based on the model service innovative solution known as service design by Stickdorn and Schneider, published that design thinking consists of four phases: exploration, creation, reflection, and implementation. (see Fig. 3 below).

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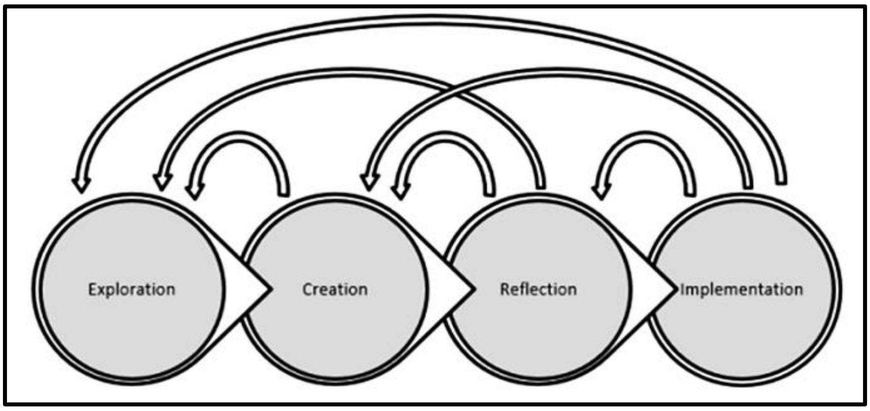

Fig. 3. Iterative service design process
(Source: Stickdorn & Schneider, 2018.)

Figure 3 indicates the model is an iterative design process composed of the following phases: 1. Exploration (understanding the culture of the customer and the actual service problem and visualizing the context), 2. Creation (generating, testing, and retesting ideas and concepts), 3. Reflection (building on ideas and concepts, prototyping, and thus closely related to stage 2), and 4. Implementation (communicating and testing the new concept, improving the prototype) (Yu, 2017; Tschimmel, 2012). This model best suits service-oriented projects that enhance user experiences and deliver value through continuous improvement. This model emphasizes exploring the service concept and its refinement through iteration. It is vital in conceptualizing service experiences rather than physical products.

Moreover, sample 3, The Double Diamond design process model, developed by the Design Council in 2005, visually represents the divergent and convergent stages of the design process, reflecting the design thinking principles. The 4D model consists of four phases: Discover, Define, Develop, and Deliver (Garbuio, 2019). The framework is illustrated in Fig. 4 below.

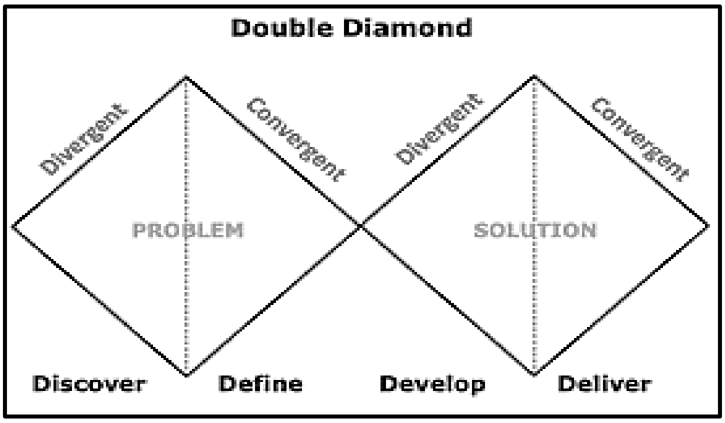

Fig. 4. Visualization of the Double Diamond model
(Source: Saad, 2020)

Figure 4 illustrates the Double Diamond model, which divides the design process into two key areas: the problem space and the solution space. The first diamond, representing problem space, starts with the Discovery phase, where designers explore and gather insights. This is followed by a phase where ideas are refined and selected. The second diamond, representing the solution space, focuses on developing and testing solutions through brainstorming and prototyping. The final stage involves finalizing and launching the best solutions. The Double Diamond model effectively visualizes the design process, making it clear and accessible for stakeholders (Saad, 2020; Melles, 2023).

The Stanford Design Thinking model, the Service Design model by Stickdorn and Schneider, and the Double Diamond model have strengths and limitations. The Stanford model is praised for its focus on user needs and creative problem-solving. However, it does not fully address material and technical factors early on, which can cause issues in manufacturing (Reynante et al., 2021). The Service Design model improves user experiences but falls short of explicitly addressing material and technical variables early in the process (Roto et al., 2021). The Double Diamond model offers a straightforward, structured process for idea development but lacks early integration of material and technical considerations (Reynante et al., 2021).

These design thinking models emphasize the importance of user-centered design, but integrating concept, material, and technical considerations is equally crucial. The conceptual design shapes the overall vision and user experience, aligning the design with its objectives (Bellos & Kavadias, 2021). Material selection impacts the product's appearance, production process, sustainability, and cost (Hernández et al., 2018). Addressing technical aspects like manufacturability and durability early on helps prevent issues and ensures smooth production (Tofail, 2018). Additive manufacturing: scientific and technological challenges, market uptake and opportunities. By combining design thinking with these elements, developers can create innovative, high-quality solutions that meet user needs and enhance the overall experience.

While design thinking has gained significant traction across various fields, existing models often fall short of fully integrating socio-technical activities and user feedback throughout the product design. Current methodologies, such as the Stanford Design Thinking model, Service Design Thinking, and the Double Diamond model, tend to focus on either the creative ideation or technical implementation phases without adequately bridging the two (Liedtka, 2020; Reynante et al., 2021). This gap limits the ability of design thinking to facilitate new technologies and dynamic capabilities. Moreover, although these methodologies emphasize understanding user behavior, there is a lack of structured approaches to incorporating multidisciplinary feedback and fostering empathy in ways that truly align with the realities and needs of users (Drouet, 2023). The proposed research addresses these gaps by developing a holistic framework integrating socio-technical principles, human interaction, and perceptual product experience into design thinking processes. This framework is intended to enhance product recognition and increase user experience.

3.0 Methodology

The research methodology for this study is designed to systematically explore the role of design thinking in influencing product development through socio-technical activity, interpreted product recognition, and perceptual product experience (PPE). Given the complexity and multidisciplinary nature of the research, a qualitative approach will be employed, utilising case studies, laboratory studies, and thematic analysis to gather in-depth insights from ceramicist experts in the design and manufacturing industries. The summary is in the flow chart of the research system. There are three stages involved in the methodology of this research, as shown below:

Phase 1: Preliminary data collected

The development of the methodology utilized in this research study was guided by the preliminary data collected and analyzed during the initial stages of the investigation by observational study (Yusuf et al., 2024). Based on observation, the existing model emphasize the important of user-centered design, however t does not fully address material and technical factors early on product design development (Reynante et al., 2021; Roto et al., 2021). This phase employed an observational study design on the triangulation of socio-technical activity, which is the concept, material, and technical characteristics in product design. This employment permitted a more in-depth exploration of the role of design thinking in influencing product development through socio-technical activity.

Phase 2: Laboratory Study (Experiment – video observations).
This study will assess and analyze data on design thinking and the socio-technical approach in product design, particularly in the industrial ceramic sector. The research will examine how existing tableware designs are developed into new products. The study will involve professional ceramists from various backgrounds in Malaysia, including those from institutions and industries. Video observations will be recorded to map and analyze design activities by participants in developing ideation for product design, following the In-Vitro Design Protocol by Anwar (2016) (Johari, 2021). The goal is to develop a socio-technical design strategy by examining design concepts, materials, and technical standards to define a unique local identity in ceramic design.

Phase 3: Validation and Reliability
This phase will ensure the research guidelines are relevant, accurate, and meaningful. Validity refers to how well a method measures what it should, covering areas like content and predictions (Abidin, 2012).
Triangulation: The study will use triangulation to increase the reliability of its design analysis findings. This means comparing data from different sources, such as initial research, experiments, video observations, and document reviews. Cross-checking this data allows the study to confirm the results and make the findings more reliable.
Member Checking: Based on the design analysis findings, the participants will review the design to ensure accuracy. This process of validating the results helps ensure that the results reflect the participants' experiences and perspectives, increasing the study's reliability. This process
Conceptual Framework: Based on the validated findings, the study will propose a framework that combines design thinking with socio-technical principles, specifically for the ceramic industry. This framework will aim to improve product recognition and ensure that design attributes inadequately address the integration of material and technical considerations at the early stages of the design process (Roto, 2020; Reynante et al., 2021).

4.0 Finding and Discussion

The research findings offer critical insights into the role of human interaction in design thinking, product recognition, and perceptual product experience (PPE). Case studies revealed that while existing design models like the Stanford Design Thinking model, the Service Design model, and the Double Diamond model are strong in user-centered design, they have gaps, particularly in integrating material and technical considerations early in the design process. Due to material constraints, these gaps often lead to challenges when moving from ideation to prototyping. The study highlights that product recognition and PPE are heavily influenced by the visual and physical attributes developed during the design process. However, traditional models lack mechanisms to ensure these attributes are technically feasible. To address these issues, the research proposes the STF approach, which integrates concept, material, and technical considerations from the outset, building on the user-centric focus of existing models. This approach introduces structured material and technical feasibility assessments at each stage, resulting in more successful and efficient product development. It is particularly suited for the ceramic industry, enabling ceramists to assess design strategies based on syntactic design characteristics empirically. (see Fig.5 below).

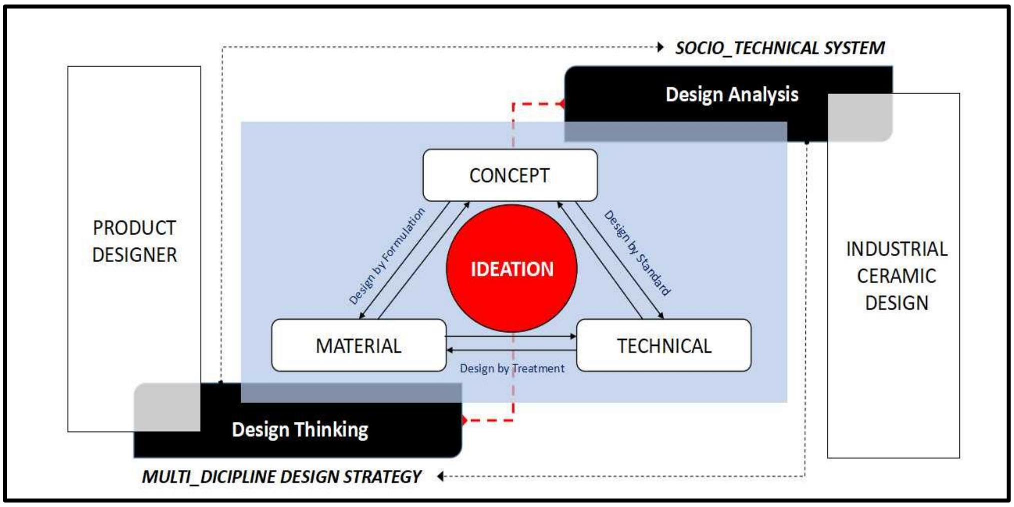

Fig 5. The Conceptual Framework of the Design Analysis Approach (STF)
(Source: Johari, 2022)

The visual representation in Fig. 5 illustrates the integration of key elements of design thinking to address gaps in existing methodologies, such as the Stanford Design Thinking model, the Service Design model by Stickdorn and Schneider, and the Double Diamond model. While offering valuable perspectives on user-centered design, these established models often fall short of thoroughly incorporating material and technical considerations throughout the design process (Reynante et al., 2021; Roto et al., 2020). When conducting research in design, particularly within the framework of integrating concept, material, and technical aspects—such as in the ConMaTech framework by Anwar (2015). He addressed that design production, especially in the specification phase, must incorporate the processes of concept, material, and technical research approaches. This approach is empirically supported by subsequent studies, such as those by Johari (2022) and Raif (2022), which underscore the relevance of this design strategy in determining product recognition based on syntactic design characteristics (Johari, 2022) further offers a triangulation design analysis of ideation activities—encompassing concept, material, and technical aspects—while Raif (2022) focuses on the design thinking process towards gestalt development and semantic representation, particularly in industrial ceramic design. Anwar (2022) expands on this by discussing how the theoretical aspect involves understanding the influence of semantics on design concepts. The practical aspect, in turn, applies this understanding to create designs that effectively communicate the intended message or feel (gestalt). By mapping out the differences in how various design ideas are interpreted, designers can make more informed decisions, ensuring the final product aligns with the desired outcomes. This approach bridges theory and practice to enhance design effectiveness.

Based on the STF approach, the findings can be categorized into three core areas: Thinking (Concept), Resources (Material), and Architectural (Technical) to enhance the design process. Lui's (2024) research supports the STF approach; it emphasizes interdisciplinary creativity for shaping user-relevant and culturally sensitive concepts, the selection of sustainable and innovative materials that align with global goals, and the technical aspect emphasizes the precise implementation of designs using emerging technologies to ensure functionality, adaptability, and scalability. By systematically incorporating these elements, the STF approach bridges the gap between creative vision and practical implementation, resulting in innovative, sustainable, and user-centered products.

Based on the findings and discussion, the STF approach's integration of Thinking (Concept), Resources (Material), and Technical (Architectural) aspects is closely correlated with Perceptual Product Experience (PPE). The conceptual aspect, which emphasizes creativity and cultural sensitivity, significantly shapes the sensory and emotional perception of the product by aligning its design with user expectations and contextual nuances. The material element, focusing on sustainable and innovative resources, enhances the tactile and visual appeal of the product, directly impacting the user's cognitive and physical interaction. Finally, the technical element ensures that the design is functional, adaptable, and scalable, improving the product's usability and reliability. This holistic integration addresses the gaps in traditional models by ensuring that the visual and physical attributes developed during the design process are aesthetically pleasing and technically feasible. Consequently, the STF approach strengthens the relationship between design thinking and PPE, ensuring that products resonate with users on a sensory, cognitive, and emotional level while maintaining practical functionality and technical excellence. By systematically incorporating these elements into the design process, the STF approach provides a more comprehensive framework for understanding how design influences PPE, bridging the gap between innovative ideas and practical implementation to create products that are engaging, user-friendly, and aligned with socio-technical principles.

The STF approach represents the concept as a "design by standard," which involves defining the overarching vision and objectives. Material represents "design by formulation," focusing on selecting and applying appropriate materials. Technical represents "design by treatment," dealing with the technical feasibility and implementation of the design. This framework highlights the importance of integrating these elements from the outset of the design process to address significant issues in industrial ceramic design. For instance, the standard treatment formulation (STF) approach in tableware design can clarify and resolve key design challenges, ensuring that products meet aesthetic and functional requirements. By incorporating these elements systematically, the STF framework offers a more comprehensive and practical approach to design thinking, ultimately enhancing product development and manufacturing processes. According to Raif (2022), design is one of the most efficient ways to add value to user-product relationships. It is influenced by the designer's knowledge structure, design level, attitude, and level of existing technology. Ceramic products can meet the needs of life, even though people are constantly developing new materials and striving to make ceramic products more diverse. Modern ceramic products' design elements include materials technology and modelling and are dominated by functional factors, which are very important for materials and modelling.

By integrating these STF approaches early in the design process, the proposed approaches bridge the gap between innovative ideas and practical implementation. The study introduces an expanded Perceptual Product Experience (PPE) framework, which considers sensory, cognitive, and emotional aspects of user experience. This holistic approach ensures that products are functional, aesthetically pleasing, and emotionally engaging, and it aligns with socio-technical activity, highlighting the importance of social and technical factors in design. The research contributes theoretically and practically. Theoretically, it refines design thinking by integrating socio-technical activity, and practically, it offers a useful framework for designers, particularly in ceramics, helping them overcome common challenges and better meet user needs and technological demands in the product manufacturing process. Integrating concept, material, and technical elements is essential for successful design. Collaborative design processes involving designers, material scientists, and engineers are crucial for effectively combining these elements. An iterative approach, refining concepts, materials, and technical solutions through testing and feedback, leads to more innovative and robust designs. A holistic approach that considers all aspects from the start results in cohesive designs that are visually appealing, functional, sustainable, and technologically advanced. Each area contributes uniquely to the design process and outcomes, and understanding their interplay is crucial for developing innovative and effective design solutions.

5.0 Conclusion& Recommendations

This research highlights the importance of combining design thinking with socio-technical activity to fill gaps in existing design methods. Traditional models, like the Stanford and Service Design frameworks, have material and technical constraints, which can hinder the practical application of innovative ideas. The study proposes a refined framework that includes concept, material, and technical feasibility from the beginning, offering a more thorough approach to design thinking. The expanded Perceptual Product Experience (PPE) framework, which addresses sensory, cognitive, and emotional aspects, ensures that products are functional and engaging. This holistic view aligns with socio-technical activity, emphasizing the balance between social and technical factors for successful design. Designers are encouraged to adopt this framework, integrating material and technical considerations early in the design phase to enhance feasibility and effectiveness. The PPE framework should address all user needs, leading to more engaging designs. Future research should examine the framework's performance across different design fields and industries to confirm its applicability and refine it with various case studies.

Acknowledgements

We would like to acknowledge The Ministry of Higher Education Malaysia for financial support and the interaction designers' generous participation in the research. This study was conducted at the National Design Centre, UiTM. Fully appreciate the Malaysia Ministry of Higher Education's financial support under the FRGS grant with Sponsorship Grant No. FRGS/1/2019/SSI07/UITM/02/8 and registered under UiTM Research Management Centre File No.600-IRMI/FRGS 5/3 (463/2019)

Paper Contribution to Related Field of Study

This research contributes to the field by introducing a refined design thinking framework that integrates material and technical considerations, emphasizing socio-technical activity, expanding the Perceptual Product Experience (PPE) framework to include sensory, cognitive, and emotional factors, and providing practical guidance for ceramic industrial design, ultimately advancing user-centered design and improving both theoretical and practical aspects of product development.

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