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THE CO-EVOLUTION OF TECHNOLOGY AND CMF IN BAMBOO FURNITURE: A NEW CLASSIFICATION FRAMEWORK

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Abstract:

As a sustainable material, bamboo's importance in the global design field is growing, leading to a significant evolution in the form and aesthetics of bamboo furniture. However, existing classification methods for bamboo furniture, which are typically based on style or function, fail to reveal the intrinsic driving force of technological innovation on the evolution of bamboo furniture design, overlooking the decisive role of technology in shaping the presentation of bamboo's CMF (Color, Material, Finish). This study adopts a qualitative case study methodology, purposively sampling a series of representative bamboo furniture products throughout their developmental history. A structured analytical framework is used to systematically explore the core processing technology and CMF characteristics of each case. Through cross-case analysis, this study proposes a new classification framework based on the co-evolution of technology and CMF. This framework identifies three unique technology-CMF paradigms: 1) the Craftsmanship Paradigm, characterized by manual skills and presenting an authentic CMF; 2) the Industrial Paradigm, driven by material engineering and presenting a standardized CMF; and 3) the Digital Paradigm, enabled by computational manufacturing and presenting a complex and customized CMF. The evolution of these three paradigms is not merely a progression of technical pathways but also reflects a shift in design philosophy. Theoretically, this framework transcends static, descriptive classifications, offering a more explanatory, dynamic analytical model. In practice, it provides designers and companies

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with a clear "technology-CMF innovation map" to serve as a reference for material innovation, product strategy, and brand differentiation.

Keywords:

Bamboo Furniture; CMF; Technological Evolution; Design Classification; Material Innovation

Introduction

Amid the global wave of sustainable development, the design community's exploration of eco-friendly materials has reached an unprecedented level. Among these, bamboo, as a "future material" that is resource-rich, fast-growing, and has carbon-negative potential, is undergoing a profound transformation from a traditional symbol of Eastern culture to a role in modern global design (Food and Agriculture Organization of the United Nations, 2020; W. Liu et al., 2018). Bamboo furniture, as a key vehicle for this transformation, has seen a dramatic evolution in its design language and product forms over recent decades, exhibiting unprecedented diversity.

However, despite the growing market interest in bamboo furniture, the academic community's systematic understanding remains relatively underdeveloped. Most mainstream furniture classification methods currently rely on traditional perspectives based on historical styles (such as Ming-style, Modernism), functionalism, or designer movements (Deng et al., 2023; Fleming, 1999; Hinchman, 2009; Hu et al., 2017; Kries et al., 2019; Smardzewski, 2015). The limitations of these classification methods become evident when applied to bamboo furniture. They tend to treat bamboo as a passive, homogeneous medium, ignoring a fundamental fact: it is the continuously advancing processing technologies that fundamentally determine bamboo's physical form, aesthetic expression, and its ultimate CMF (Color, Material, Finish) possibilities (Ashby & Johnson, 2013; Karana et al., 2010; Krippendorff, 2005). Therefore, existing furniture classification systems cannot reveal the inherent driving force behind the evolution of bamboo furniture design.

Table 1: Examples of Mainstream Furniture Classification Methods

	literature	time	author	Viewpoint
1	Furniture Design	2015	Smardzewski	Furniture classification system based on function
2	History of furniture: A global view	2009	Hinchman	Furniture classification paradigm based on Chinese and Western historical styles
3	Atlas of furniture design	2019	Kries et al.	A historical classification of furniture based on style and designer
4	The Semiotics of Furniture Form	1999	Fleming	Furniture classification paradigm based on semiotics

5	Research on Bamboo Furniture Design Based on D4S	2023	Deng et al.	Bamboo furniture classification system based on materials and technology

Source: Author's Own Drawing

Thus, this study identifies a clear academic gap: the current lack of a theoretical framework that can systematically connect "bamboo processing technology" with the "final CMF presentation of the product". To bridge this gap, this study aims to answer the following core questions: 1) How does the development of bamboo processing technology drive the evolution of bamboo furniture's CMF? 2) What kind of co-evolutionary relationship exists between technology and CMF? 3) Is it possible to construct a new, more explanatory classification framework based on this co-evolutionary relationship, one that is distinct from traditional methods?

To answer these questions, this study sets the following specific research objectives and scope:

- **Overall Objective:**

To construct a dynamic classification framework for bamboo furniture with "technology-CMF co-evolution" as its core.

- **Specific Objectives:**

To systematically analyze and elucidate how the development of bamboo processing technology drives the evolution of bamboo furniture's CMF (Color, Material, Finish).
To construct a new, more explanatory, and dynamic classification framework based on the co-evolutionary relationship between technology and CMF.

- **Research Scope:**

This study will focus on bamboo furniture as the core case study subject, systematically selecting representative products from pre-industrial craftsmanship to contemporary digitally manufactured outputs. The research spans the three key technological eras—traditional craftsmanship, industrialization, and digital manufacturing—to ensure a comprehensive analysis.

The contributions of this study are twofold: theoretically, it provides a new analytical model for material-driven design history and theory research, a model that emphasizes the core role of technology in shaping the aesthetics of material culture (Manzini, 1986) ; in practice, it offers contemporary designers and businesses a clear "technology-CMF" knowledge map that can serve as a reference for material innovation, product line planning, and brand differentiation.

Literature Review

CMF Theory and Its Role in Product Design

CMF, an abbreviation for Color, Material, and Finish, consists of three core elements that define a product's surface aesthetics and sensory quality. It is not a simple superposition of three independent elements but a highly integrated, collaborative design system (Van Kesteren, 2008). As the most direct point of user-product interaction, CMF constitutes the "perceptual interface" of a product, completing a crucial first communication even before the user delves into its functions. Therefore, in contemporary product design, CMF has long transcended its subordinate, decorative role to become a strategic core component for shaping product perception, optimizing user experience, and building brand value (Nawar et al., 2024).

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First, CMF is the silent language that shapes product perception. A product communicates its value, quality, target audience, and even usage methods to users through its CMF (Krippendorff & Butter, 2008). Through "product semiotics," CMF guides the user's initial judgment and expectations, with its persuasiveness taking effect even before a functional demonstration (Ashby & Johnson, 2013).

Second, CMF is a key dimension for building a deep user experience. It is not only about visuals but also about deepening the experience through touch and other senses. The temperature and texture of a material (warm or cool, soft or hard, rough or smooth) and the finish's tactile feel (skin-friendly, damped, or precise) directly affect the user's emotional resonance (Karana et al., 2010). This sensory pleasure and emotional resonance triggered by CMF are central to "emotional design" (Norman, 2007). Recent studies have further emphasized the importance of cross-sensory CMF experiences, suggesting that in multi-modal interactive and immersive environments, CMF can influence product experience through the coupling of color, touch, and sound (Lv et al., 2022). Furthermore, the application of data-driven and AI technologies is gradually making CMF design predictable and optimizable (C. Liu & Kim, 2023).

Finally, CMF is a core asset for building brand value and identity. In a highly competitive market, a unique CMF strategy is a key means of achieving brand differentiation. From Tiffany's robin-egg blue to Apple's iconic use of metal and glass, successful brands have shaped their unique brand identity through a stable and forward-looking CMF system (Verganti, 2009). A mature CMF system not only enhances brand recognition but also continuously reinforces its value proposition in the minds of consumers.

In summary, CMF is not a "beautification" step at the end of the product development process but a core link that runs through preliminary research, strategic positioning, and production implementation. Understanding the intrinsic value and formation mechanism of CMF is the foundation for conducting material-driven design research. However, CMF is always constrained and inspired by material properties and their processing technologies. Therefore, to deeply understand the CMF evolution of bamboo furniture, one must first explore the developmental trajectory of bamboo processing technology.

The Development Trajectory of Bamboo Processing Technology

The evolution of CMF in bamboo furniture is not a purely aesthetic choice but is driven and defined by innovations in processing technology. Looking at its developmental trajectory, it can be roughly divided into three stages: the Traditional Craftsmanship Era, the Industrialization Era, and the Digital Manufacturing Era. These three stages represent different paradigms in the human relationship with bamboo: from conforming to its natural form, to transforming its physical structure, to imbuing it with new expressive power through digital logic.

The Traditional Craftsmanship Era

For a long time, the application of bamboo was dominated by craftsmanship, with a core philosophy of "working with the grain"—respecting and utilizing the raw form and natural properties of bamboo (Liese & Köhl, 2015). Artisans relied on experience to perform bending, weaving, carving, and joinery on bamboo poles. In this paradigm, design was limited by the material's dimensions and node characteristics. The CMF, therefore, presented a high degree

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of "naturalness": the color was the pale yellow or greenish hue of the bamboo, the material retained its natural fibrous texture and nodes, and the finish showed clear traces of handiwork.

The Industrialization Era

In the latter half of the 20th century, to overcome the heterogeneity of natural bamboo (inconsistent size, susceptibility to cracking, difficulty in standardization), a turning point in bamboo material engineering occurred. Through technologies like Laminated Bamboo Lumber (LBL) and Strand Woven Bamboo (SWB), bamboo was transformed into stable, uniform industrial raw materials (Gupta et al., 2015). This technology broke the original form of bamboo, allowing it to be interchangeable with materials like wood and man-made boards, greatly expanding the CMF boundaries of bamboo furniture. The CMF characteristics of this stage are uniformity, stability, and predictability, gradually breaking away from the limitations of traditional "natural" representations.

The Digital Manufacturing Era

Entering the 21st century, digital manufacturing became a new paradigm for bamboo processing. Integrated CAD/CAM processes enable a tight coupling between design and manufacturing (Chryssolouris et al., 2009). Key technologies include CNC machining, laser cutting, parametric design, and 3D printing (Oxman, 2010). Building upon the homogeneous materials provided by industrialization, these processes further enhance the expressiveness of CMF. For example, CNC can create specific micro-textures on the bamboo surface, directly affecting touch and luster; laser cutting not only increases structural complexity but also imparts a unique visual texture to the edges; and parametric modeling allows designers to control how bamboo grain is revealed, achieving customized CMF effects (Lo et al., 2025). Furthermore, recent experimental research has shown that combining digital processes with new modification technologies can create new materials like transparent and biomimetically dyed bamboo, giving bamboo furniture CMF unprecedented expressive power (Wu et al., 2021; Yu et al., 2023).

Current State of Bamboo Furniture Design Research

In recent years, bamboo furniture, as a product with both cultural heritage and ecological value, has become a focus of attention across multiple disciplines. However, a systematic review of existing literature reveals that research mainly concentrates on three relatively independent areas: cultural symbolism interpretation, sustainability assessment, and structural engineering analysis. Although these studies have made their own contributions, they have, to some extent, overlooked the direct relationship between technology and CMF.

First, cultural research emphasizes the symbolic meaning and aesthetic connotations of bamboo. Scholars have explored the symbolism of bamboo in Chinese and East Asian cultures, such as "integrity" and "humility" (Dlamini et al., 2022; W. Liu et al., 2018), as well as its aesthetic implications in traditional furniture and Zen contexts. This type of research reveals the cultural roots of bamboo furniture but does not delve into the generation mechanism of CMF.

Second, sustainability assessment is another research hotspot. Numerous studies use Life Cycle Assessment (LCA) to quantify the advantages of bamboo furniture in terms of carbon footprint and energy consumption (Chen et al., 2020; Van Der Lugt et al., 2006). While these studies highlight the green value of bamboo, their focus is on the production process, lacking analysis

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and evaluation of the final product's CMF characteristics.

Finally, structural engineering research focuses on the mechanical properties and durability of bamboo (Mitra, 2014; Sinha et al., 2014). This type of research ensures the safety and stability of bamboo furniture but leans towards "performance optimization," failing to connect material processing with CMF expression.

In summary, existing studies have provided rich results on cultural, environmental, and engineering levels, but they generally treat CMF as a "given outcome". There is a lack of systematic research to trace the causal chain between its evolution logic and technological innovation. Therefore, this study does not view CMF as a static surface but as a constantly evolving interface driven by technology, aiming to propose a classification framework that reveals the "technology-CMF" co-evolution mechanism in bamboo furniture.

Methodology

To delve into the complex co-evolutionary relationship between the CMF (Color, Material, Finish) of bamboo furniture and its processing technology, and to answer the exploratory questions posed in this study, a qualitative case study method was adopted. This method is widely considered an effective way to deeply understand complex social phenomena within a specific context and is suitable for answering the exploratory questions of this study (Yin, 2017). Through in-depth analysis of specific cases, this study gains rich, contextualized insights, ultimately constructing a new classification framework (White & Cooper, 2022).

Research Path Design

The methodology design of this study follows a systematic logical process. First, through "purposive sampling," a series of cases that represent milestones in the history of bamboo furniture development were carefully selected. Second, a structured analysis archive was established for each case to systematically collect and record its technology and CMF data. Finally, through cross-case analysis, patterns, associations, and differences between different cases were identified, from which three types of technology-CMF co-evolution paradigms were extracted to build the classification framework.

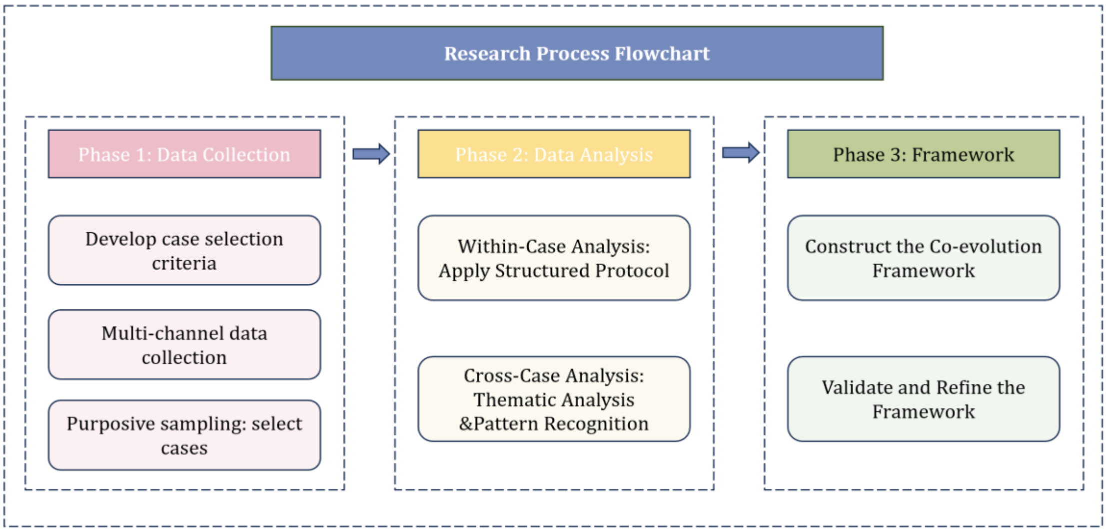

Figure 1: Research Flowchart

Source: Author's Own Drawing

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Data Collection

Case Selection Criteria

This study adopted a purposive sampling strategy to rigorously select samples that could represent key turning points in the evolution of bamboo furniture. The specific criteria are as follows:

- **Technological Representation:** The core processing technology used in the case must be a significant breakthrough or a typical representative of its era. Examples include joinery and weaving in the craftsmanship tradition, laminated gluing in the industrialization stage, and contemporary exploration of CNC and composite materials.
- **CMF Uniqueness:** The case must demonstrate novelty in the color, material, and finish of bamboo, breaking through existing aesthetic perceptions to become an important aesthetic example of its time.
- **Market or Design Influence:** The case must have had a demonstrative effect in the industry or design community, possessing identifiable value for dissemination and imitation.

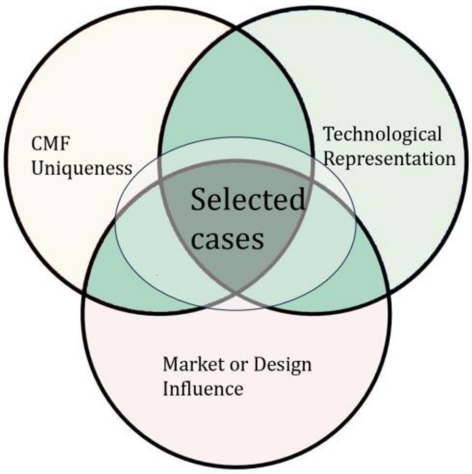

Figure 2: Diagram of Case Selection Criteria

Source: Author's Own Drawing

In addition, this study specifically emphasizes:

- **Time Span:** The selected cases cover the period from the rise of modernism in the mid-20th century to the present (approximately 1950-2025), to track the evolution of bamboo furniture from the pre-industrial to the digital era.
- **Location & Context:** The case selection takes into account design practices from different cultural contexts, both Eastern and Western, including the modernization of Eastern traditional craftsmanship, the application of Nordic minimalism, and cross-cultural design exploration in a globalized context.

Multi-channel Data Collection

To ensure the reliability and validity of the study, a multi-channel data collection strategy was adopted to cross-verify the data for each case (Triangulation). The specific data sources include:

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- **Academic Literature:** Retrieval of academic journal articles and monographs related to bamboo technology, furniture design history, and material culture from databases such as Scopus, Web of Science, and Google Scholar.
- **Design Publications and Archives:** Consulting authoritative design magazines and online archives such as Designboom, Dezeen, and Architonic.
- **Official & Primary Sources:** Collecting product catalogs, technical specifications, and interviews from brands and designers (e.g., IKEA, Reforest Design, Moso group).
- **High-Resolution Visual Data:** Detailed visual analysis of high-resolution photos, technical drawings, and video materials of the case products to accurately interpret their CMF characteristics.

Purposive Sampling

Ultimately, 14 cases were selected as analysis subjects, balancing the integrity of historical evolution with the operational requirements of qualitative research. The cases include traditional works by anonymous artisans as well as contemporary representative design projects from IKEA, MOSO, and ETH Zurich.

Table 2: Selected 14 Bamboo Furniture Products or Project Samples

Case 1 **Designer/Brand:** Anonymous Artisans	**Case 5** **Designer/Brand:** Shih Ta-Yu	**Case 9** **Designer/Brand:** Anthony Marschak	**Case 13** **Designer/Brand:** Lotte van Laatum
			
Case 2 **Designer/Brand:** Anonymous Artisans	**Case 6** **Designer/Brand:** IKEA of Sweden	**Case 10** **Designer/Brand:** Various Designers	**Case 14** **Designer/Brand:** ETH Zurich (DBT)
			
Case 3 **Designer/Brand:** Anonymous Artisans	**Case 7** **Designer/Brand:** MOSO	**Case 11** **Designer/Brand:** Gao Yang	

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Case 4 **Designer/Brand:** Shih Ta-Yu	**Case 8** **Designer/Brand:** Reforest Design	**Case 12** **Designer/Brand:** Robert van Embricqs
		

Source: https:// taobao.com; https://k.sina.com.cn; https://www.chinadesigncentre.com; https://www.ikea.cn; https://www.mosogroup.cn; https://reforestdesign.com; https://www.architonic.com; https://www.designboom.com; https://www.pinterest.com; (Van der Lugt, 2008)

Data Analysis Framework

The data analysis process of this study is divided into two main steps: within-case analysis and cross-case analysis.

- Step 1: Within-Case Analysis. To ensure systematic data collection and comparability of analysis, a Structured Analysis Protocol was established for each case, covering the three dimensions of core technology, CMF analysis, and design philosophy. This protocol helps researchers analyze from both a micro and macro level. See the table below for details:

Table 3: Case Study Analysis Protocol

Dimensions	Sub-dimensions	Core analysis issues
A. Core Technology	A1. Main processing technology	Key technologies for transforming native bamboo
	A2. Generated material form	The intermediate material form produced by the process
B. CMF Analysis	B1. Color	What's the color scheme like?
	B2. Materiality	What are the main texture and morphological characteristics?
	B3. Finish	What is the final surface treatment process?
Design philosophy	C1. The relationship between people and materials	What roles do people and materials play in furniture production? What is the relationship between them?

Source: Author's Own Drawing

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- Step 2: Cross-Case Analysis. After completing the single-case analysis, the study moves to the cross-case comparative analysis stage. This stage uses the method of Thematic Analysis (Braun & Clarke, 2006) , systematically comparing data on dimensions A, B, and C across different cases to find patterns, associations, and evolutionary rules. For example, systematically comparing the significant differences in the C, M, and F dimensions between "cases using traditional bending techniques" and "cases using laminated bamboo technology". Ultimately, these identified and recurring "technology-CMF" combination patterns are clustered, distilled, and abstracted to form the empirical basis for the core finding of this study—the three major technology-CMF paradigms. The entire analysis process is a rigorous inductive process from specific data to abstract patterns and finally to a theoretical framework.

Results

By using the methodology described in Chapter 3, this study conducted a systematic analysis of a series of carefully selected, milestone bamboo furniture cases. The analysis process strictly followed the structured protocol (see Table 3 in the methodology section), aimed at deconstructing the core technology, CMF characteristics, and the underlying design philosophy of each case. A cross-case comparative analysis revealed three recurring and internally consistent "technology-CMF" combination patterns. These patterns constitute the core findings of this study and are categorized into three unique technology-CMF paradigms. This chapter will first present a detailed analysis of representative cases for each paradigm and then build the final classification framework based on this analysis.

Analysis of Representative Cases for Each Paradigm

Paradigm I: Craftsmanship Paradigm—CMF of Authenticity

Cases under this paradigm demonstrate a relationship between humans and bamboo based on "conformation" and "dialogue". Its technological system aims to maximize the use and highlight of bamboo's natural properties.

Table 4: Analysis of Selected Cases under the Craftsmanship Paradigm

Case	Core Technology	CMF Analysis	Design Philosophy
	• Fire Bending • Mortise & Tenon Joinery • Hand Weaving	**C:** Bamboo yellow, showing a natural luster. **M:** Preserves the rounded shape, bamboo joint characteristics, and natural fiber texture of the bamboo pole. **F:** Light and elegant, with a resilient woven seat.	The physical properties of bamboo are perfectly integrated with the aesthetic philosophy of literati, making it a model of "authentic CMF".

Source: Author's Own Drawing

- **Core Technology:** The core of this paradigm is a reliance on manual skills and respect for the original form of bamboo. The design and production process follow the natural properties of the material. Key techniques include fire bending, manual splitting of bamboo strips, weaving, joinery, and carving.

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- **CMF Characteristics:** The CMF under this paradigm presents a strong "authenticity," aiming to highlight rather than conceal the material's natural origin.
  - **C (Color):** Primarily the natural color of bamboo (pale green, bamboo yellow), or the color that gradually darkens with time and oxidation. The range of color choices is limited and directly related to the physical state of the material.
  - **M (Material Form & Texture):** Retains the nodes and straight longitudinal grain of the bamboo. It emphasizes the natural fibrous structure of the material.
  - **F (Finish):** Relies on manual techniques such as weaving, carving, and polishing. The surface details are uncontrollable, which also brings uniqueness and irreplaceability.

Summary: The Craftsmanship Paradigm is centered on the three elements of "natural-unique-cultural," emphasizing the authenticity, cultural significance, and manual traces of the material, which strengthens the emotional connection between the material and the user.

Paradigm II: Industrial Paradigm—CMF of Standardization

This paradigm marks a thorough revolution in material engineering, with the core goal of "deconstructing and reconstructing" non-homogeneous natural bamboo into stable, uniformly specified industrial raw materials to fit modern mass production systems.

Table 5: Analysis of Selected Cases under the Industrial Paradigm

Case	Core Technology	CMF Analysis	Design philosophy
	•Laminated Bamboo Lumber - LBL • Mass Production	**C:** A uniform, predictable natural bamboo color. **M:** A completely flat, smooth, and homogeneous surface free of natural imperfections. **F:** A simple geometric form that is easy to package and DIY assembly.	Transformed into industrialized materials, standardized CMF

Source: Author's Own Drawing

- **Core Technology:** The manufacturing of Laminated Bamboo Lumber (LBL) and Strand Woven Bamboo (SWB), which transforms bamboo into predictable, mass-producible boards and blocks.
- **CMF Characteristics:** The CMF characteristics of this paradigm are "standardization" and "de-naturalization," which allow bamboo to break free from its original form and integrate into modern industrial production systems.
  - **C (Color):** The color selection is greatly enriched. Almost any color can be achieved through processes such as steaming, carbonization, and artificial dyeing. The CMF color is completely separated from the original state of the material.
  - **M (Material Form & Texture):** Laminated bamboo retains some of the bamboo grain characteristics but presents them in a regularized, smooth, and homogeneous

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form. Strand woven bamboo, on the other hand, completely reconstructs the material, with a texture that is close to wood.
- ◦ **F (Finish):** Mechanized processing brings a more refined surface finish, enabling the modularization of components. Its predictability and standardization meet the needs for functionality and durability. It also isolates the user from the direct contact with the bamboo itself.

Summary: The Industrial Paradigm enables "standardized-efficient-high-performance" bamboo furniture production, overcoming the unpredictability of bamboo. In the CMF dimension, it emphasizes performance and regularity while also losing the uniqueness of bamboo.

Paradigm III: Digital Paradigm—CMF of Complexity and Customization

This paradigm is built upon the standardized bamboo boards provided by the Industrial Paradigm, using computer-aided design and manufacturing (CAD/CAM) technologies for "secondary creation". Its core is precise processing driven by digital logic.

Table 6: Analysis of Selected Cases under the Digital Paradigm

Case	Core Technology	CMF Analysis	Design philosophy
	• Parametric Design • CNC-aided Fabrication	**C:** The original color of the material. **M:** Natural bamboo poles are combined with precision-machined industrial bamboo panels. **F:** Complex, non-standard geometric forms generated by algorithms have strong digital aesthetic characteristics.	It has achieved complex structures that cannot be completed with traditional technology, greatly expanding the application boundaries of bamboo.

Source: Author's Own Drawing

- **Core Technology:** Precise processing driven by digital logic. Representative technologies include CNC machining, laser cutting, parametric design, and 3D printing.
- **CMF Characteristics:** The CMF under this paradigm presents unprecedented "complexity" and "customization". It reintroduces uniqueness on top of industrialized substrates, but this uniqueness originates from algorithms rather than nature.
  - ◦ **C (Color):** Color typically inherits from the boards provided by the Industrial Paradigm. The focus is not on changing the color but on altering light reflection through processing to create rich light and shadow effects.
  - ◦ **M (Material Form & Texture):** CNC milling and algorithmically generated textures can create parametric ripple patterns, complex three-dimensional reliefs, or precise geometric patterns on flat bamboo boards. In terms of form, it can achieve streamlined curved surfaces and complex openwork structures that are impossible with traditional craftsmanship.

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- **F (Finish):** "Machining as Finish". The precise path left by the machine tool on the bamboo surface itself constitutes the final texture and decoration. This is a new type of aesthetic defined by digital precision (Gershenfeld, 2012). Digitalization also offers the possibility of "re-creating tradition," such as the parametric design of bamboo weaving and the combination of 3D-printed components with natural bamboo (Lo et al., 2025).

Summary: Under the Digital Paradigm, bamboo furniture presents a hybrid "natural-artificial" CMF characteristic. It provides a new path for the contemporary cultural and unique expression of bamboo furniture.

Cross-Paradigm Comparison and Visual Presentation

To more intuitively demonstrate the relationships and evolutionary path among the three paradigms, this study conducted a cross-paradigm comparison. The progression from the Craftsmanship Paradigm to the Industrial Paradigm and then to the Digital Paradigm is the result of continuous technological development and the deepening of technological intervention. In this process, the CMF of bamboo furniture undergoes a leap-forward transformation.

- **Color (C):** From the natural gradients of the Craftsmanship Paradigm → to the artificial uniformity of the Industrial Paradigm → to the algorithmic generation and personalization of the Digital Paradigm.
- **Material & Texture (M):** From natural texture → to engineered reconstruction → to artificial-natural hybrid generation.
- **Finish (F):** From manual traces → to precise standardization → to design-driven processing and multi-material integration.

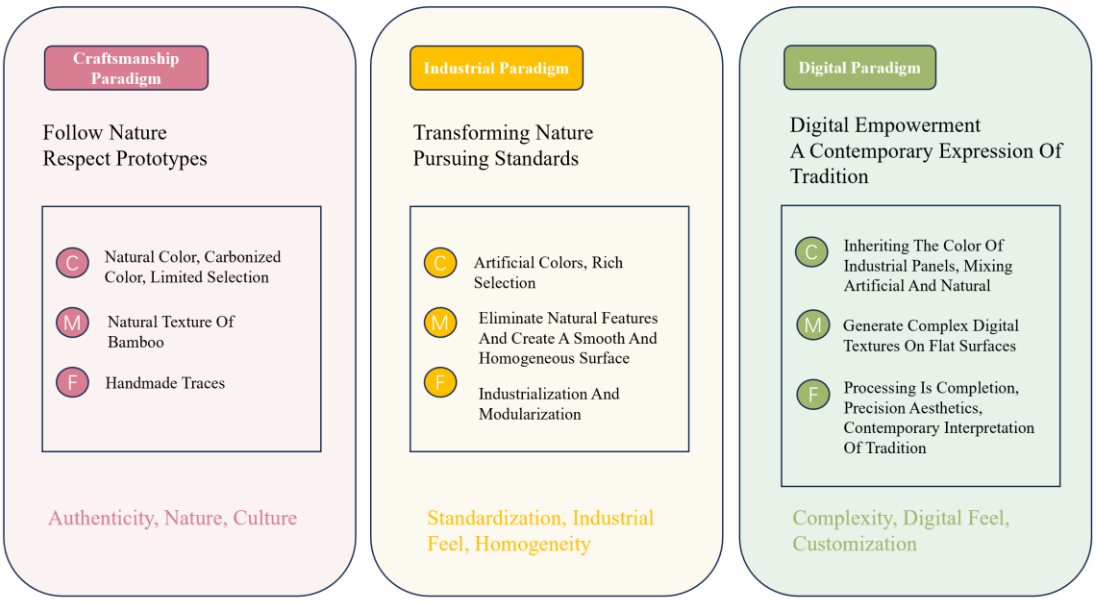

Figure 3: Comparison of CMF Characteristics across the Three Paradigms

Source: Author's Own Drawing

The three paradigms constitute a progressive path of co-evolution between bamboo furniture technology and CMF. Under the Craftsmanship Paradigm, CMF presents natural and cultural characteristics; under the Industrial Paradigm, CMF presents engineered and standardized

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characteristics; while under the Digital Paradigm, CMF presents digital and re-cultural characteristics. This evolution not only reflects the increasing depth of technological intervention but also reveals a shift in CMF expression from natural to artificial, and then to a hybrid and re-cultural state, embodying the core logic of "co-evolution".

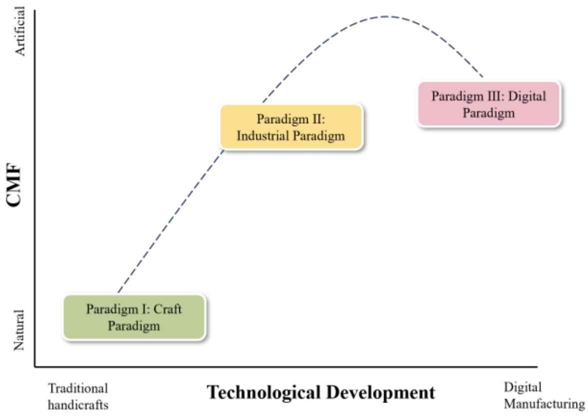

Figure 4: Technology-CMF Co-evolution Framework
Source: Author's Own Drawing

Discussion

The technology-CMF co-evolution framework proposed in this study not only provides a new classification system for bamboo furniture but, more importantly, it reveals the philosophical shifts and practical logic behind the evolution of design. This chapter will discuss the framework's interpretation, the significance of its contributions, and its limitations and future outlook.

Interpreting the Framework: From the "Poetics of Materials" to the "Grammar of Technology"

The three paradigms identified in this study reflect a fundamental transformation in the relationship between humans and materials, an evolution from the "Poetics of Materials" to the "Grammar of Technology".

In the Craftsmanship Paradigm, the designer or artisan plays the role of a "listener" and "interpreter". They engage in a dialogue with the material, following bamboo's inherent physical properties and morphological characteristics. The design process is filled with respect for and conformance to the material's nature. This is a "material-centric" design philosophy, where the final CMF is an expression of the material's own characteristics, emphasizing the beauty of naturalness and serendipity.

In the Industrial Paradigm, technology is no longer a tool for conforming to the material but a force for transforming it. Bamboo is deconstructed and reshaped, its natural properties being overridden by an industrial logic to become a standardized substrate that can be precisely controlled and predicted. Here, technology becomes the "grammar" of CMF, dictating the content and form that CMF can express. Designers create within a given set of rules, reflecting a "human-centric" or "technology-centric" ideology, with CMF presenting an industrialized character that emphasizes consistency, functionality, and efficiency.

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In the Digital Paradigm, CMF and technology present a more complex and dialectical relationship. It is built on the standardization of the Industrial Paradigm, but uses algorithms and computation to regenerate complexity and uniqueness. If industrial grammar seeks standardization, then digital grammar can express complexity. The designer becomes the "author of the grammar," capable of creating new forms that transcend both nature and traditional industrial aesthetics. This signifies a "post-human-centric" trend, where human creativity and machine intelligence co-create, pushing the expressive potential of materials into new and unknown territories.

Research Contributions

Academic Contribution

The "Technology-CMF" framework of this study has a dual theoretical value.
First, it transcends traditional classification methods, providing a new analytical dimension for design history and design theory research. Traditional classifications based on style or function are descriptive and static; they can tell us "what the product looks like" but are less able to explain "why the product looks the way it does". The "Technology-CMF" framework of this study is explanatory and dynamic, as it reveals the "generative mechanism" behind the forms of material culture. It establishes a clear causal relationship by treating technology as the independent variable and CMF as the dependent variable, thereby allowing for a deeper understanding of the intrinsic logic of artifact evolution.

Second, this "Technology-CMF" analytical model has the potential to serve as a general method that can be applied to design research for other materials. Almost all natural materials have undergone a similar path of technological evolution. Materials such as wood and ceramics also follow a similar logic. Therefore, this framework has the potential to become a general theoretical tool for analyzing the evolution of design culture for different materials.

Industry Contribution

The framework also provides practical insights. First, it offers designers a "CMF innovation map," which can help them engage in conscious and strategic innovation rather than relying on accidental inspiration. Designers can clearly select the required technology-CMF path based on their design goals.

Second, the framework provides a reference for corporate brand positioning. Companies can plan their product lines based on market tiers: a "Craftsmanship Heritage Series" for the high-end market; a "Durable Standardized Series" for the mass market; and an "Exploratory Series" to showcase innovation. This approach can provide some guidance for companies in brand identification and differentiation strategies driven by CMF.

Limitations and Future Outlook

As an exploratory qualitative study, this research has some limitations. First, while the case selection followed strict criteria, it could not cover all important types of bamboo furniture, and some marginal practices may have been missed. Second, the core of this study is to construct the objective link between "technology-CMF," and it does not delve into a quantitative analysis of the impact of different CMF combinations on user perception and emotional response.

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Future research can be expanded in the following directions:

- **Integration of Framework with User Perception:** Combining the technology-CMF paradigms with user aesthetic preferences, quality perception, and emotional responses. Empirical methods such as semantic differential scales, user interviews, and even eye-tracking and electroencephalography (EEG) could be used to verify the impact of different paradigms on user experience.
- **Cross-cultural Comparison:** Exploring the differences in how users from different cultural backgrounds understand the CMF of bamboo furniture. For example, the cultural identity of bamboo in East Asian and European markets may lead to different levels of acceptance for the craftsmanship or digital paradigms.
- **Challenges of the Digital Paradigm:** With the development of artificial intelligence and generative design, the framework needs to respond to new changes in "human-machine co-creation" contexts. How to utilize machine intelligence to expand the possibilities of CMF while preserving the cultural value of the material is a question worthy of in-depth exploration in the future.

In conclusion, the "technology-CMF co-evolution framework" of this study not only deepens the research on bamboo furniture design but also provides a new analytical path for the evolution of design culture across different materials.

Conclusion

This study aims to address the limitations of existing bamboo furniture classification systems, which fail to systematically reveal the intrinsic logic of design evolution. By deeply exploring the relationship between technological development and CMF (Color, Material, Finish) expression, this study constructs a "technology-CMF co-evolution framework" that for the first time systematically reveals the evolutionary logic of bamboo furniture from the Craftsmanship Paradigm, to the Industrial Paradigm, and finally to the Digital Paradigm. The research shows that this evolution is not merely a change in form but a profound shift in design philosophy from the "Poetics of Materials" to the "Grammar of Technology".

The contributions of this study are twofold: academically, the framework transcends static descriptions based on style or function, providing an explanatory, dynamic analytical model; in practice, it provides designers with a CMF innovation reference and offers insights for corporate brand positioning and product strategies, while also providing theoretical support for the formulation of industrial policies.

Bamboo is a fast-regenerating and eco-friendly material. How to transform the advantages of bamboo resources into industrial advantages in today's rapidly developing technology is an urgent problem to be solved. It is hoped that this study can provide some theoretical reference for the formulation of relevant industrial policies, contributing to the promotion of sustainable development and the achievement of the UN's Sustainable Development Goals.

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