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Hierarchical Structuring of Product Color Combinations Using ISM

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Abstract: This research bridges the gap between artistic color selection and scientific modeling, offering designers a robust tool for optimizing color combinations across diverse product categories. The methodology integrates quantitative analysis with qualitative insights from color psychology. Development of a systematic color combination model for product design utilizing Interpretive Structural Modeling (ISM) methodology to address the complexity of color selection. Integration of established color theory principles, psychological factors, and hierarchical modeling through ISM to create a structured decision-making framework. Enhancement of product aesthetics and market appeal through informed, systematic color choices grounded in theory and consumer psychology research.

Keywords: Product color system; Color module; Interpretive structural model; Color

1. Introduction

Color combinations profoundly influence consumer perception, emotional response, and purchasing decisions. Yet selecting optimal color schemes remains a complex challenge for product designers, requiring consideration of cultural contexts, target demographics, and product categories.Traditional approaches to color selection often rely on intuition and experience rather than systematic analysis, leading to inconsistent outcomes and missed opportunities for market differentiation, Hsiao et al. (2013). This study introduces Interpretive Structural Modeling (ISM) as a novel approach to structure the multitude of factors influencing effective color combinations. ISM provides hierarchical clarity to interrelated design elements (Lee et al., 2010). Research Objectives: Develop a comprehensive ISM-based model, integrate color theory with psychological insights, validate through real-world applications, and provide actionable guidelines for practitioners (Lee et al., 2010). Color harmony principles guide designers toward aesthetically pleasing combinations, while color psychology reveals how hues influence emotions and behaviors. Existing frameworks provide foundational knowledge, but lack systematic structuring of interdependent factors affecting real-world color selection decisions in product design contexts。

2. The artwork of "Composition A" by Mondrian

Single hue with varying shades, tints, and tones creating unified, harmonious designs (Warfield, 1973; Lin & Wang et al., 2006). Adjacent colors on the color wheel producing serene, comfortable visual experiences. Opposite colors creating maximum contrast and vibrant, energetic combinations. Four-color schemes (tetradic) providing rich, diverse palettes requiring careful balance. Triadic Three evenly spaced colors offering balanced, vibrant schemes with visual interest (Fig. 1).

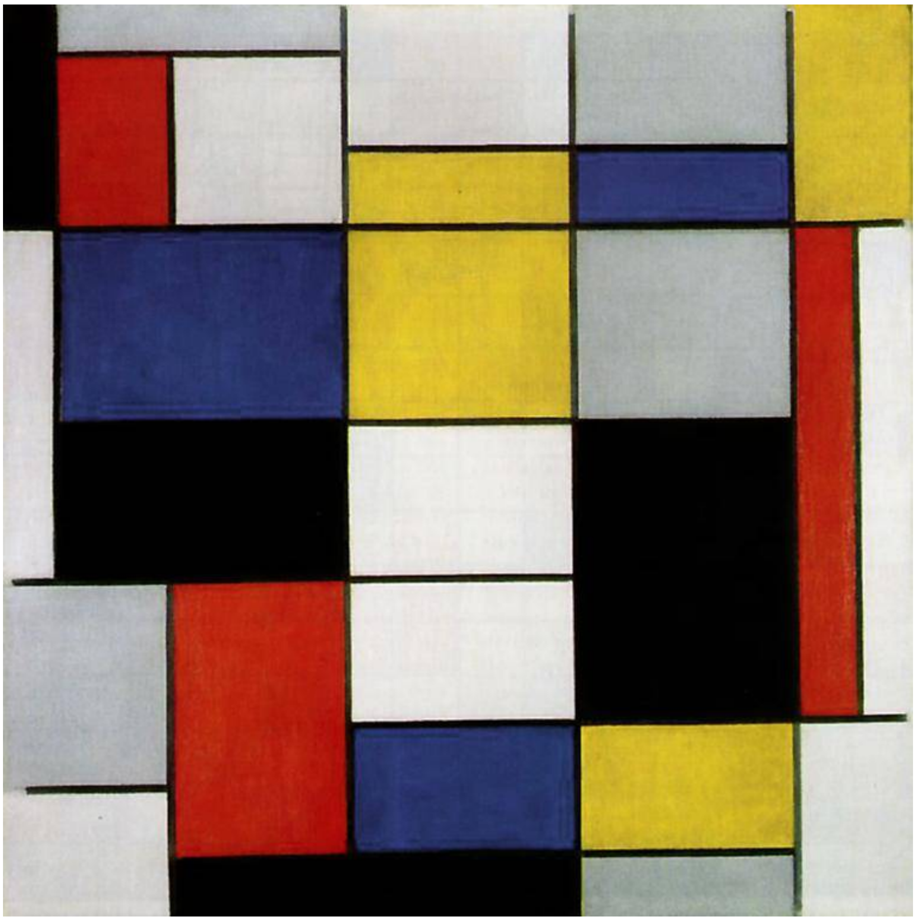


Fig 1. The artwork of "Composition A" by Mondrian.

2.1. Theoretical Background

Product color design plays a critical role in shaping user perception, emotional response, and brand identity. Color combinations not only influence aesthetic appeal but also affect usability, product recognition, and consumer preference. Previous studies have shown that effective color planning requires the integration of perceptual, psychological, and contextual factors, making color design a complex and multi-dimensional decision-making process. As a result, systematic analytical methods are increasingly adopted to support designers in managing the interdependencies among color-related factors.Interpretive Structural Modeling (ISM) is a methodology originally developed for analyzing complex systems with multiple interacting elements. ISM enables the transformation of qualitative expert knowledge into a structured and hierarchical model by identifying relationships among system components. Through iterative decomposition, ISM clarifies causal structures and reveals driving and dependent elements within a system. Due to its ability to handle ambiguity and interrelated factors, ISM has been widely applied in fields such as engineering management, strategic planning, and systems analysis. In recent years, its application has been extended to design research, where it serves as an effective tool for organizing design attributes and decision criteria.In the context of color design, ISM provides a theoretical foundation for structuring color combination factors that are often subjective and difficult to quantify. By establishing hierarchical relationships among color attributes, designers can better understand how fundamental color elements influence higher-level color schemes. This structured approach supports rational decision-making while preserving the creative flexibility inherent in design practice.Furthermore, modular color systems and standardized color encoding methods, such as the DIC color system, offer a means to translate abstract color concepts into practical design components. When combined with ISM, these systems facilitate the systematic exploration of color combinations and enable consistent communication across design and production processes. The integration of ISM with modular color encoding thus forms a robust theoretical basis for developing structured, repeatable, and scalable product color combination models.Overall, the theoretical framework of this study is grounded in design theory, systems analysis, and decision science. By bridging qualitative design thinking with structured analytical modeling, this approach provides a comprehensive foundation for investigating and optimizing product color combination strategies.By means of the color modular design of partially common color, products which possess different types of imagery can be created. As a result, it is important to effectively utilize modular design methods from the beginning to establish the corresponding relation between various color modules. And this approach assists in the diversified designs of products. The methods adopted by this study and their related theories are explained respectively as follows:

2.2. Basic concepts and the development process of ISM

A powerful technique for analyzing complex systems by transforming unclear, poorly articulated mental models into visible, well-defined structures showing relationships among elements (Diabat et al., 2011; Lin et al., 2013). ISM organizes interrelated elements into hierarchical levels, revealing driving and dependent factors through systematic analysis of contextual relationships (Hsiao & Liu, 2010) as follows.

Draw the D+R_D-R element distribution graph.

ISM has proven valuable in decision-making contexts, strategic planning, and system analysis, Interpretive Structural Modeling (ISM) is widely applied in decision-making, strategic planning, and system analysis, and is therefore appropriate for organizing and clarifying color combination factors. Based on the reachability matrix, the sum of each row is defined as D, while the sum of each column is defined as R. The values of D + R and D − R are then calculated to form the reachability matrix determinants, as illustrated in Fig. 2. Plotting D + R and D − R on a binary coordinate system enables a clear distinction between key issues and target factors. Furthermore, this approach facilitates the classification of elements into independent, interdependent, driving, and dependent categories (Lee et al., 2010), as presented in Fig. 3.

a_{ij}	C_1	C_2	C_3	C_4	C_5	C_6	C_7	D	D + R	D–R
C_1	1	0	0	0	0	0	0	1	8	–6
C_2	1	1	1	0	1	1	1	6	8	4
C_3	1	0	1	0	1	0	1	4	10	–2
C_4	1	0	1	1	1	0	1	5	6	4
C_5	1	0	1	0	1	0	1	4	10	–2
C_6	1	1	1	0	1	1	1	6	8	4
C_7	1	0	1	0	1	0	1	4	10	–2
R	7	2	6	1	6	2	6			

Fig 2. Reachability matrix determinant.

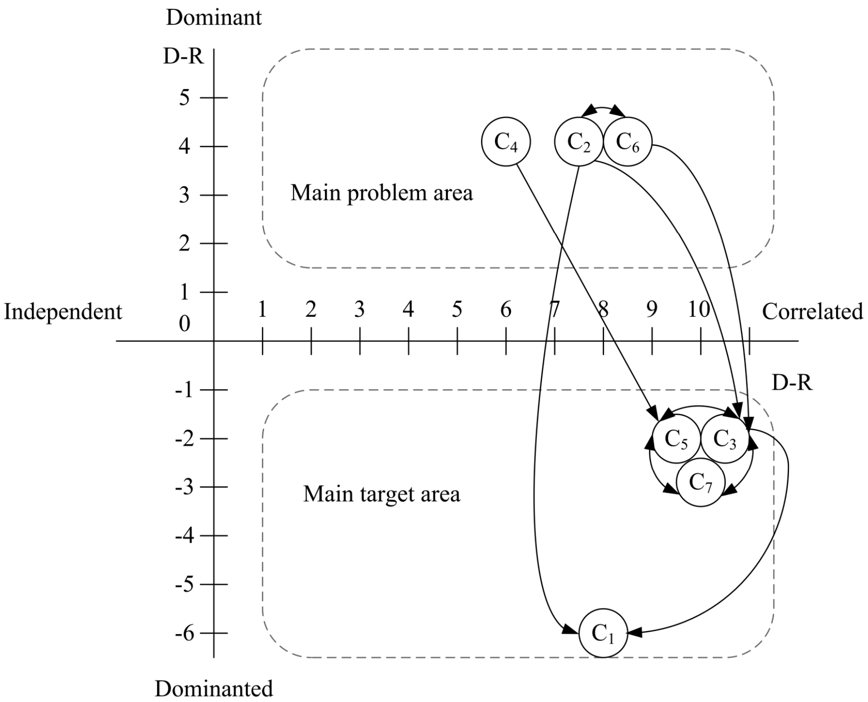


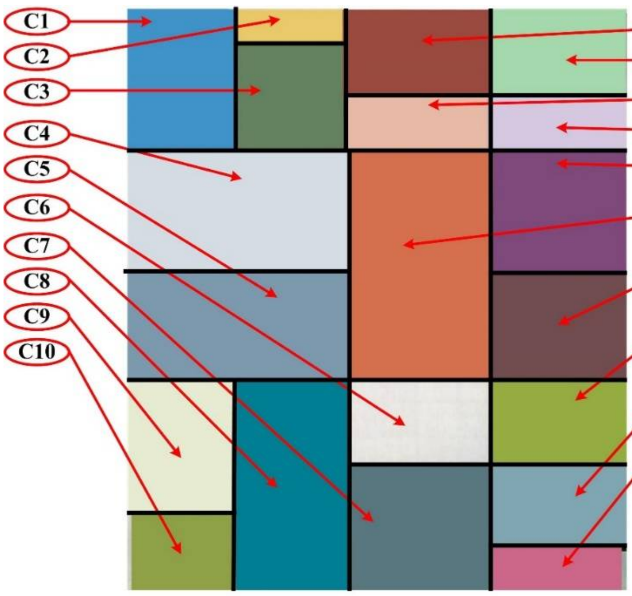
Fig 3. A graph representing D+R_D-R element distribution.

3. Cluster Analysis

Cluster analysis is performed on preprocessed data to classify objects into distinct groups according to similarity patterns. Objects exhibiting comparable characteristics are assigned to the same cluster, while those with dissimilar attributes are separated into different clusters. Within each cluster, data demonstrate high internal homogeneity, whereas significant heterogeneity exists across clusters. This method relies on variations in data density and similarity. Initially, specimens are mapped into an n-dimensional feature space, where n represents the number of variables, and pairwise distances or similarity measures among specimens are calculated. In this study, major market user groups were selected as specimens to identify and classify distinct clusters.

4. Application of Case Study and Case Verification

To validate the feasibility and effectiveness of the proposed ISM-based color combination model, a case study approach was employed. The case study was designed to examine how the hierarchical structure derived from ISM calculations can be applied in a real-world product color design context. By selecting representative product color schemes from the market, the proposed model was tested for its ability to organize complex color relationships and support systematic decision-making.In the application phase, the color schemes identified in the case study were encoded using the DIC color system to ensure consistency and modularity. These encoded color combinations were then mapped onto the hierarchical framework generated by the ISM analysis. This process allowed designers to clearly identify driving color factors, intermediate elements, and dependent color schemes within the overall structure. By following the hierarchical relationships, designers were able to evaluate how changes in fundamental color attributes influenced higher-level color combinations, thereby improving the clarity and efficiency of color selection during the design process.Case verification was conducted by comparing the ISM-derived results with expert evaluations and market observations. Design professionals were invited to review the hierarchical model and assess whether the identified key color combinations aligned with their practical design experience. The results indicated a high degree of consistency between the model outcomes and expert judgments, confirming the reliability of the proposed approach. Additionally, the structured classification of color schemes corresponded well with prevailing market trends, further supporting the practical validity of the model.The verification process also demonstrated that the proposed framework can reduce ambiguity in color decision-making by transforming subjective design preferences into an explicit and traceable structure. By providing a visual and analytical representation of color relationships, the model facilitates communication among designers, engineers, and decision-makers, particularly in multidisciplinary design teams.Overall, the case study and verification results confirm that the ISM-based color combination model is both applicable and effective in practical product design scenarios. The proposed approach not only supports rational color planning and modular design implementation, but also offers a reliable method for validating color strategies in alignment with expert knowledge and market demands. This study adopts Mondrian-style composition as its conceptual framework, while the DIC encoding system is applied to support the modularization of product color design [6]. The case study illustrated in Fig. 4(a) comprises twenty distinct color combinations, with their corresponding DIC codes presented in Fig. 4(b).



(a)

C1	DIC 2592s
C2	DIC 2075s
C3	DIC 2322s
C4	DIC 2196s
C5	DIC 2382s
C6	DIC 583s
C7	DIC 2371s
C8	DIC 252s
C9	DIC 2086s
C10	DIC 362s
C11	DIC 2487s
C12	DIC 2120s
C13	DIC 468s
C14	DIC 635s
C15	DIC 227s
C16	DIC 2526s
C17	DIC 2251s
C18	DIC 2548s
C19	DIC 428s
C20	DIC 2466s

(b)

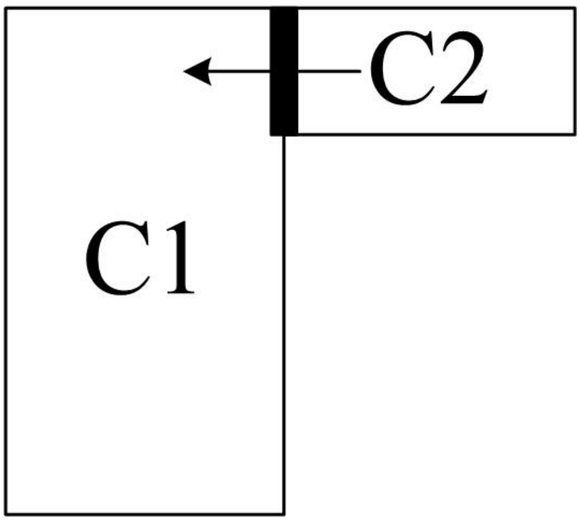
Fig 4. The figure of case study design.

4.1 ISM Calculations

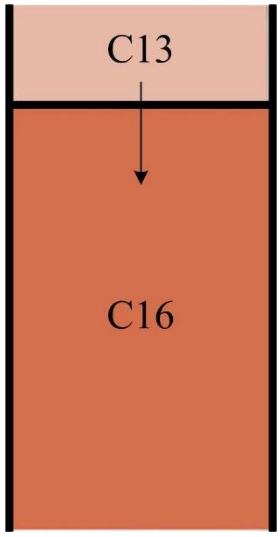
The ISM calculation process begins with the construction of a relational matrix derived from pairwise comparisons among color schemes. Expert evaluations are used to determine whether a directional influence exists between each pair of elements. Based on these judgments, a binary adjacency matrix is established, where a value of 1 indicates the presence of a direct relationship and 0 indicates no relationship. This matrix serves as the foundation for subsequent ISM computations.To obtain the reachability matrix, the adjacency matrix is combined with the identity matrix to account for self-influence. Boolean operations are then repeatedly applied until the matrix reaches convergence, ensuring that both direct and indirect relationships among color schemes are fully captured. The resulting reachability matrix represents the complete set of influence paths within the system.

From the reachability matrix, the driving power (D) and dependence power (R) of each element are calculated by summing the values in the corresponding rows and columns, respectively. The indicators D + R and D − R are subsequently derived to evaluate the overall importance and causal role of each color scheme. Specifically, D + R reflects the degree of interaction between an element and the system, while D − R distinguishes driving elements from dependent ones.Based on these indicators, the reachability matrix is reorganized to identify interaction relationships and hierarchical levels. Elements with identical reachability and antecedent sets are grouped into the same level, and higher-level elements are progressively removed to reveal lower-level structures. Through this iterative process, a multi-level hierarchical model is established, clearly illustrating the structural relationships among color schemes.Overall, the ISM calculation procedure provides a transparent and systematic means of transforming qualitative judgments into a structured analytical model, enabling a deeper understanding of the interdependencies and hierarchical organization of product color combinations.Pairwise comparisons among different color schemes were conducted to construct the ISM relational matrix. Through this process, directional relationships were identified, such as smaller color blocks influencing larger ones and weaker color schemes linking to stronger schemes, as illustrated in Fig. 5(a) and Fig. 5(b). Certain color schemes exhibited no relational links and were therefore excluded from subsequent connections. Based on the analogous color blocks and schemes shown in Fig. 6(c), the color relational matrix was established.

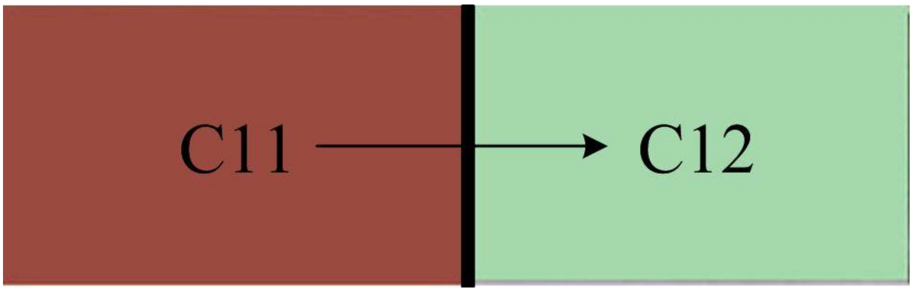
By incorporating the identity matrix into the 20 × 20 relational matrix and applying Boolean operations until convergence, the reachability matrix among color schemes was obtained. From this matrix, interacting elements were identified as those satisfying the condition a1, forming an interaction matrix. The reachability matrix was then reorganized by tracing inter-element relationships to generate a rearranged matrix. Following the fifth step of the ISM procedure described in Section 3.1, the reachability matrix was structured into a six-level hierarchy, and the corresponding ISM hierarchical model is illustrated in Fig. 6.Subsequently, in accordance with the sixth step of the ISM analysis outlined in Section 3.1, the values of D + R and D − R were calculated and used to construct the causal relationship diagram based on these indicators.



(**a**)



(**b**)



(c)

Fig 5. ISM-related connection graphs.

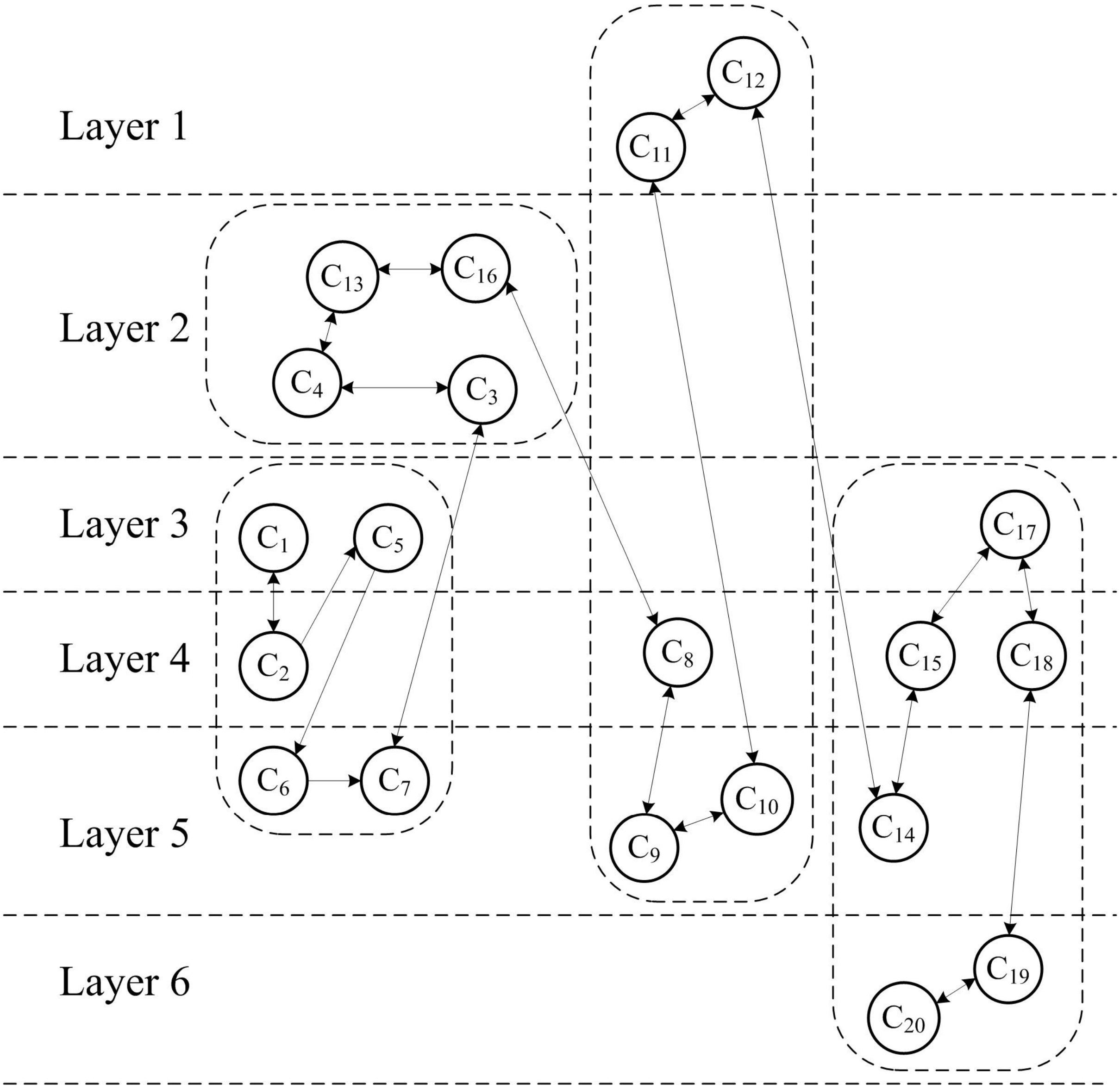


Fig 6. The flowchart of ISM correlations.

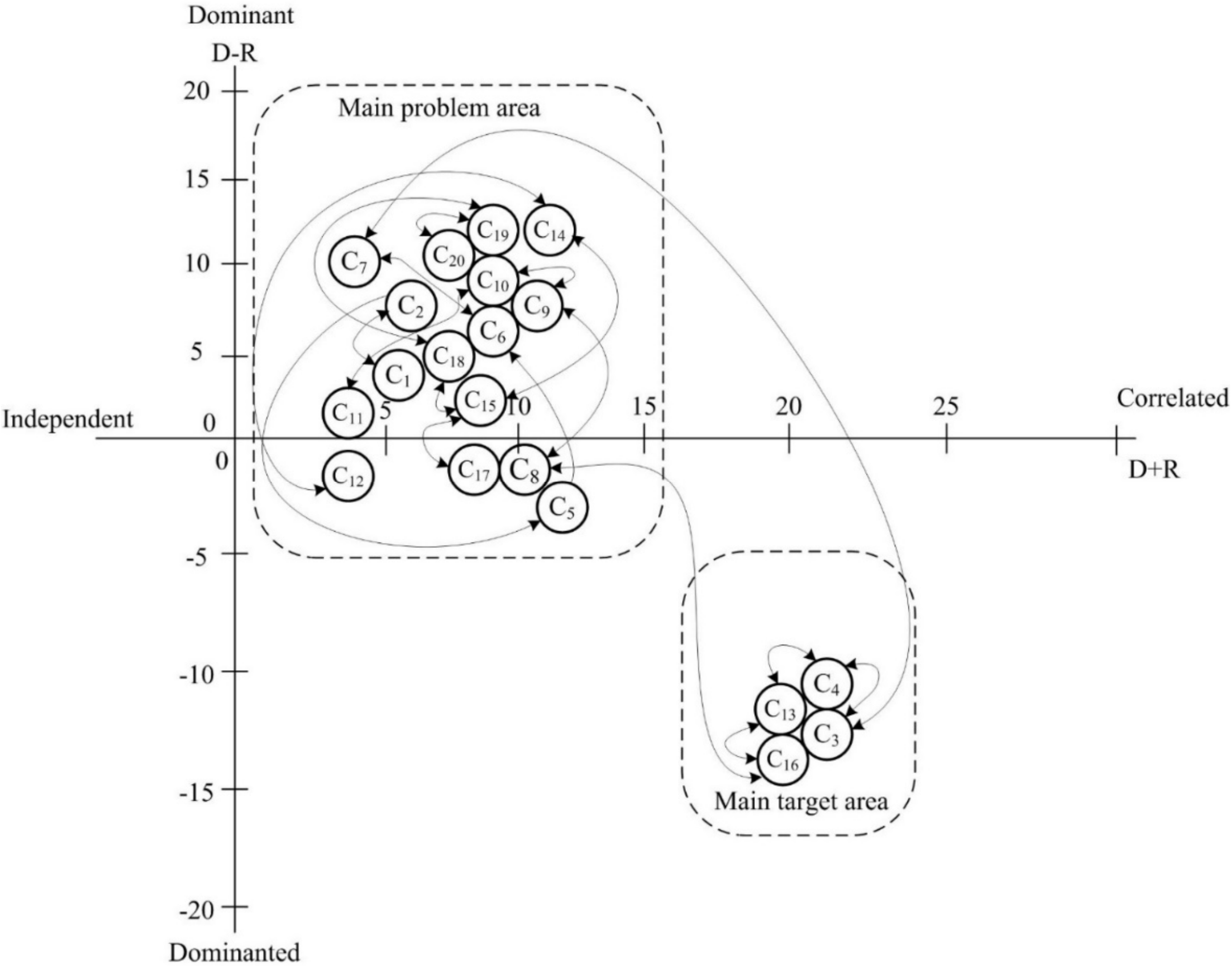


Fig 7. The relation chart of D+R and D-R.

(**a**) DIC 2592s

(**b**) DIC 2371s

(**c**) DIC 2371s

(**d**) DIC 252s

Fig 8. Real case studies of colors corresponding to clusters.

5. Conclusions and Suggestions

This study proposes a systematic approach to constructing a product color combination model by integrating Interpretive Structural Modeling (ISM) with quantitative analytical procedures. By applying ISM to the analysis of color schemes, the complex interrelationships among color combination factors were effectively structured into a clear hierarchical framework. The results demonstrate that ISM is not only suitable for decision-making and system analysis, but also highly applicable to the organization and interpretation of product color design elements, which are often characterized by ambiguity, subjectivity, and interdependence.

Through pairwise comparisons and Boolean operations, a reachability matrix was established, allowing the identification of driving, dependent, independent, and interactive color elements. The subsequent hierarchical decomposition revealed a multi-level structure that clarifies how fundamental color attributes influence higher-level color schemes. The calculation of D + R and D − R values further enabled the classification of causal and effect factors, providing designers with an intuitive understanding of which color combinations play dominant roles and which are primarily influenced by others. These findings confirm that the proposed model can reduce complexity in color decision-making and support more rational and transparent design processes.From a practical perspective, the results offer valuable guidance for product designers and design managers. By identifying key driving color factors, designers can prioritize critical elements during the early stages of color planning, thereby improving efficiency and consistency in product color development. The modular structure based on the DIC encoding system also facilitates flexible color configuration and supports the standardization of color modules across different product lines. This approach is particularly beneficial for industries that require rapid customization while maintaining visual coherence, such as consumer electronics, furniture, and lifestyle products.In addition to its practical contributions, this study provides methodological value for design research. The application of ISM extends its use beyond traditional engineering and management contexts into the domain of visual and color design, demonstrating its adaptability to qualitative–quantitative hybrid problems. The proposed framework can serve as a reference for future studies seeking to analyze complex design factors with hierarchical dependencies.Several limitations should be acknowledged. First, the color schemes analyzed in this study were derived from a specific design context, which may limit the generalizability of the findings. Second, expert judgment was involved in the pairwise comparison process, which inevitably introduces a degree of subjectivity. Future research is therefore encouraged to expand the sample size, incorporate cross-cultural color preferences, and integrate objective data sources such as user perception experiments or AI-based color analysis.In conclusion, the ISM-based color combination model developed in this study offers a structured, systematic, and practical tool for product color design. By bridging design theory and analytical modeling, it contributes to both academic research and real-world design practice, and provides a solid foundation for further exploration of intelligent and data-driven color design methodologies. Acknowledgments: In this section, you can acknowledge any support given which is not covered by the author's contribution or funding sections. This may include administrative and technical support, or donations in kind (e.g., materials used for experiments).

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Conflicts of Interest: The author declares no conflict of interest.

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