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International Journal of Combinatorial Optimization Problems and Informatics, 16(3), May-Aug 2025, 278-299. ISSN: 2007-1558.
https://doi.org/10.61467/2007.1558.2025.v16i3.712

Fuzzy modeling of the relationship between fashion themes, colors, and styles in a garment

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Abstract. Fashion themes, along with suitable colours and design styles, are crucial for creating garments that align with consumer preferences. Traditionally, designers have relied on intuition; however, fuzzy logic has gained recognition as a formal method for modelling the ambiguous nature of fashion design. By applying fuzzy techniques, designers can quantify the relevance of colours and styles to specific fashion themes, leading to a more structured decision-making process. This study aims to develop a fuzzy modelling framework for women's swimwear design, formalising the relationships between fashion themes, colours, and styles. Expert evaluations contributed to establishing relational matrices for colour elements and design styles, which were validated by comparing them with expert opinions. The ultimate goal of this research is to develop practical guidelines for designers to enhance the alignment of fashion themes with colours and styles, particularly for mass-customised swimwear, utilising a data-driven approach.

Keywords: fuzzy modeling, fashion themes, swimwear design, color and style alignment, mass customization.

Article Info
Received January 28, 2025
Accepted April 14, 2025

1 Introduction

Design elements, such as fashion themes, colors, and styles, shape the fashion industry. These elements are significant in markets such as women's swimwear. In the swimwear market, designs must be both visually appealing and functionally suitable for various body types and use contexts (Fan et al., 2004). Fashion themes with suitable colors and design styles are essential in creating garments aligned with the preferences of the consumers (Wang et al., 2015). Fashion themes guide color and design. Designers have traditionally relied on intuition, but there is a growing interest in formalizing this process through fuzzy logic (Dong et al., 2020). Fuzzy logic deals with partial truth and is well-suited for modeling the ambiguous and imprecise nature of fashion design (Zadeh, 1965; Chen et al., 2009). By applying fuzzy techniques, designers can quantify the relevance of specific colors and styles to different fashion themes; consequently, this form of work provides a more structured approach to decision-making in the design process (Wang et al., 2015).

The fashion industry is becoming increasingly competitive. Consumers want personalized and consistent garments. This is especially true for mass-customized products, where it is crucial to count with fashion themes and colors, and styles aligned with one another (Wang et al., 2016; Dong et al., 2020). Despite the potential advantages of using fuzzy logic in fashion design, limited research comprehensively explores the application of these techniques to model the relationships between fashion themes, colors, and styles (Dong et al., 2020). Much research focuses on isolated design aspects, such as color theory or style selection. It must fully consider the interactions between these elements and the main fashion themes (Chen et al., 2009).

The primary objective of this research is to develop and validate a fuzzy modeling framework that formalizes the relationship between fashion themes, colors, and styles in women's swimwear design to enhance the traditional design process (Wang et al., 2015). Using fuzzy logic, the primary objective is to establish a formalized relationship between fashion themes and color elements, specifically hue, value, and chroma. This involves a data collection process in which experts evaluate the relevance of different color elements to specific fashion themes. With the obtained information, it is constructed a fuzzy relational matrix (Chen et al., 2009; Wang et al., 2016). The second objective is to explore the relationship between fashion themes and design styles, including patterns, waist levels, and bust designs. By means of expert assessments and fuzzy techniques, we should construct a relational matrix that models these relationships (Dong et al., 2020; Wang et al., 2015).

The third objective is to validate the accuracy and practical relevance of the fuzzy models by comparing the model outputs with the expert panel's perceptions. This validation process ensures that the models are practically applicable to real-world design problems (Chen et al., 2009). Finally, the research aims to translate the findings into practical guidelines and insights that designers can use to optimize the alignment of fashion themes with color and style elements in the context of mass-customized swimwear design (Fan et al., 2004; Wang et al., 2016). This research aims to align fashion themes with colors and styles using a data-driven approach.

To build the fuzzy models, the following steps were taken: The study used fuzzy sets to represent linguistic variables, such as the relevance of colors and styles to fashion themes. These fuzzy linguistic variables describe the relationship between fashion themes and design elements and were quantified on a fuzzy scale from -3 to +3. Using expert evaluations, fuzzy relational matrices were created for both the color elements and design styles. These matrices captured expert opinions on the relevance of different colors and styles to specific fashion themes. The fuzzy values from the relational matrices were converted into precise scores using defuzzification techniques. This process allowed for a clearer interpretation of the expert evaluations.

Experts utilized a seven-point scale to evaluate the relevance of various color and style elements to different fashion themes. Their assessments were then converted into fuzzy numbers, which were used to create fuzzy sets and matrices. The fuzzy models were validated by comparing the results with the perceptions of the expert panel. This approach ensured that the models accurately reflected real-world design challenges. Ultimately, the study aimed to translate the findings into practical guidelines to assist designers in better-aligning fashion themes with colors and styles in the context of mass-customized swimwear.

The paper is organized into eight distinct sections. Section 2 reviews the literature, Section 3 describes the materials and methods used, Section 4 proposes the fuzzy modeling framework, Section 5 presents the experimentation, Section 6 presents the outcomes of these models, and Section 7 concludes with recommendations for future research.

2 Literature review

Fashion themes are central to the design of garments. They shape collections with broader cultural, social, and emotional narratives, which are translated into design elements such as colors, fabrics, and styles (Barnes & Lea-Greenwood, 2006). Fashion themes also influence brand identity and market positioning; for example, Aleem et al. (2024) use a systematic review and a text-mining approach to analyze 73 articles on luxury fashion consumption, aiming to clarify, rationalize, and critically interpret the literature on luxury fashion consumption; identify the core topic, create an integrative framework of core constructs; and offer research gaps and suggest a research agenda for future studies.

From an aesthetic perspective, fashion themes should resonate with consumers (Jackson & Shaw, 2009). For instance, Wei (2024) notes that the fast fashion industry has benefited from new media promotion, enabling it to operate efficiently and stay current with the latest products and promotions. Color theory is crucial in fashion design as it influences how garments are perceived and the emotions they evoke. Elliott & Maier (2014) state that different colors elicit specific emotions and associations; they review theoretical and empirical work that examines the link between color and psychological functioning in humans beyond color aesthetics. They demonstrate that color can convey significant meaning and have a profound impact on people's emotions, cognition, and behavior. Certain color combinations are essential for achieving visual harmony or contrast in a garment. Different color schemes can impact the aesthetic and market appeal of a design (Fehrman & Fehrman, 2004). Consideration of hue, saturation, and brightness also contributes to the perception and psychological impact of the garment (Cunningham, 2017). Cultural and social contexts also influence the emotional and psychological effects of color (Madden, et al., 2000). This cultural variation necessitates a nuanced approach to color selection in fashion design, particularly for global brands serving diverse markets. In this sense, a study conducted by McLean et al. (2020) offers an empirical perspective on the antecedents and outcomes of consumer attitudes toward retailers' mobile commerce (m-commerce) applications, also known as apps.

Swimwear design styles range from classic one-piece suits to more contemporary designs, such as cut-outs and high-waisted bikinis, catering to diverse consumer preferences and body types (Cox & Dittmar, 1995). Swimwear design has a delicate balance of beauty and functionality. Competitive swimwear is engineered to minimize resistance and enhance movement in the water, while fashion swimwear is crafted to reflect the latest trends and captivate the eye (Li et al., 2024). This study carried out by Li et al. (2024) covers the aesthetics, comfort, speed enhancement, and other additional functions of swimsuits, summarizes the research progress in each relevant area, and predicts potential hotspots based on analysis. It is predicted that smart textiles and technologies will be applied more widely to swimsuits for real-time monitoring and instruction, intelligent drag reduction, and energy harvesting, among other applications. Factors such as the target market and the intended purpose of the swimwear shape the design approach (Rocamora & Smelik, 2015). The design of swimwear requires how diverse styles complement the body and how consumers perceive them. For instance, a 2023 study conducted by Tsawaab highlighted the significance of body positivity in swimwear design.

Fuzzy modeling is a mathematical approach that addresses uncertainty and subjectivity in design decision-making by allowing for degrees of truth. It helps model complex, an uncertain relationship in garment design (Zadeh, 1965). Fuzzy modeling has been applied in various fields, such as architecture, industrial design, and fashion. In garment design, it has been used to customize garments based on individual preferences and measurements (Wang et al., 2015; Wang et al., 2016). Fuzzy modeling is valuable for considering multiple design criteria simultaneously, such as fit, fabric performance, and aesthetic appeal in mass-customized garments. Fuzzy multi-criteria decision-making techniques facilitate the evaluation and prioritization of these criteria, enabling more informed design decisions (Chen et al., 2009). Fuzzy cognitive maps analyze the impact of garment design elements on aesthetics. This process aims to help designers understand how color, style, and fabric interact (Dong et al., 2020). This research employs fuzzy modeling to investigate the relationships between fashion themes, colors, and styles, with the goal of providing a structured framework for designers.

3 Materials and methods

This section outlines the methodology for developing and validating a fuzzy modeling framework that captures the relationships among fashion themes, colors, and styles. It begins by introducing fuzzy sets and fuzzy linguistic variables, which are essential for quantifying the relevance of various design elements to specific fashion themes. The construction of fuzzy relational matrices and the defuzzification process, which transforms fuzzy data into actionable results, is also discussed. Additionally, the section describes how color elements (hue, value, and chroma) and design styles (e.g., patterns, waist levels) are integrated into the model, using expert evaluations to establish formalized relationships.

Furthermore, this section details the composition of the expert panel and the setup of the data collection processes. It outlines two main data collection designs: one examines the relationship between fashion themes and colors, while the other explores the connection between fashion themes and design styles. These processes utilize fuzzy logic to capture expert insights on how color and style elements align with various fashion themes, providing a structured approach to fashion design decisions, particularly in the realm of mass-customized swimwear.

3.1 Description of related concepts

3.1.1 Fuzzy modeling framework

Fuzzy logic is a mathematical approach that allows us to model uncertainty and imprecision in data using degrees of truth. This is particularly useful in fields such as fashion design, where the relationships between different design elements (such as colors, styles, and themes) can be subjective and not easily quantified. In this research, fuzzy logic is applied to model the relationships between fashion themes, colors, and design styles in women's swimwear design.

The fuzzy modeling framework outlined here employs fuzzy sets to represent linguistic variables, such as the relevance of a design element to a specific fashion theme. These fuzzy sets are defined by membership functions that determine a degree of membership for each element in the set. For instance, a fashion theme may be associated with a particular color, and the membership function measures the relevance of that color to the theme.

In the fuzzy model, triangular membership functions are used, as shown in Figure 2. Triangular membership functions are commonly used in fuzzy logic because they are simple to implement and interpret. A triangular function is defined by three points: the peak (representing the highest membership degree) and the two base points, which define the range of values where the membership degree decreases linearly. These functions clearly quantify the degrees of relevance for each color or style element relative to the fashion themes. The fuzzy relational matrices created from expert evaluations utilize these triangular membership functions to indicate the level of relevance between fashion themes and design elements. The matrix illustrates the fuzzy relationships among the elements, facilitating structured decision-making in the design process.

The fuzzy modeling involves several key components.

Fuzzy sets: Represent linguistic variables such as 'relevancy' between fashion themes. They are characterized by membership functions which define the degree of belonging to a set.

Fuzzy Linguistic Variables: The study employs fuzzy linguistic variables to describe the relationships between fashion themes and design elements, which are defined on a scale ranging from -3 to +3 to indicate relevance.

Fuzzy Relational Matrices: The fuzzy modeling framework utilizes fuzzy relational matrices to capture expert evaluations of the relevance of colors and styles to specific fashion themes, which are then used to compute the overall alignment between design elements and fashion themes.

Defuzzification: To gain valuable insights, fuzzy values in the relational matrices are converted into precise scores, indicating the relevance of each design element to the fashion themes.

This framework provides detailed analysis for designers to align colors and styles with specific fashion themes.

3.1.2 Formalization of garment colors

Color is also a crucial factor in garment design. It can embody people's aesthetic demands. In garment design, designers focus on the visual and psychological feeling of colors, which is caused by three basic color properties: Hue, Value, and Chroma. Hue is the basic character that distinguishes and names various colors. Value property of color can describe all shades of color from white to black. Chroma expresses the vivid or pure degree of color. In practice, these three properties of color cannot be separated. The first color order system developed was the *Munsell Color System* (MacAdam, 1981), in which color consciousness is described accurately.

In the Munsell color system, any color can be calibrated using three coordinates: Hue, Value, and Chroma. Hue, Value, and Chroma can express color perception, and different color feelings can cause different psychological responses. The primary psychological sensations include changes in temperature, light, and heaviness, as well as shifts in space and emotion. Using the Munsell color system, we can easily select suitable colors that match our aesthetic preferences and psychological feelings about garment design.

Let $HUE = \{HUE_1, HUE_2, \ldots, HUE_{v_1}\}$be the set of Hue elements. As only one hue is selected for each garment color (in this case, it is swimwear), we use a hue vector, i.e., $hue = (hue_1, hue_2, \ldots, hue_{v_1})$ in the following calculation presented in Eq. 1, we have

$$hue_i = \begin{cases} 1, & \text{if the hue element } HUE_i \text{ is selected} \\ 0, & \text{otherwise} \end{cases} \qquad i = 1,2,\ldots,v_1. \tag{1}$$

Let $VALUE = \{VALUE_1, VALUE_2, \ldots, VALUE_{v_2}\}$be the set of Value elements. As only one value is selected for each garment color (in this case, it is swimwear), we use a value vector, i.e. $value = (value_1, value_2, \ldots, value_{v_2})$ in the following calculation presented In Eq. 2, we have

$$value_i = \begin{cases} 1, & \text{if the value element } VALUE_i \text{ is selected} \\ 0, & \text{otherwise} \end{cases} \qquad i = 1,2,\ldots,v_2. \tag{2}$$

Let $CHROMA = \{CHROMA_1, CHROMA_2, \ldots, CHROMA_{v_3}\}$be the set of Chroma elements. As only one chroma is selected for each garment color (in this case, it is swimwear), we use a chroma vector, i.e. $chroma = (chroma_1, chroma_2, \ldots, chroma_{v_3})$ in the following calculation presented in Eq. 3, we have

$$chroma_i = \begin{cases} 1, & \text{if the chroma element } CHROMA_i \text{ is selected} \\ 0, & \text{otherwise} \end{cases} \qquad i = 1,2,\ldots,v_3. \tag{3}$$

Let $c = (HUE_x, VALUE_y, CHROMA_z)$ be a specific color vector, and all color vectors constitute a set of Colors C, obtained by combining all color properties.

Denote $v = v_1 + v_2 + v_3$as the total number of all possible garment color elements. We have $v_1 \times v_2 \times v_3$ vectors corresponding to the colors.

Let a block matrix *COLOR*, presented in Eq. 4, be the color matrix, defined as

$$COLOR = \begin{bmatrix} hue & 0 & 0 \\ 0 & value & 0 \\ 0 & 0 & chroma \end{bmatrix}_{3\times v} \quad (4)$$

3.1.3 The design style elements

The modular design of a garment involves breaking it down into multiple components based on its structure. This approach is highly flexible, enabling users to create diverse design outcomes by modifying and rearranging various modules. By adding or changing a module, designers can generate a wide range of new design options. This method significantly expands the possibilities for garment design solutions, enabling the meeting of personalized needs for diverse consumers. The modular design method offers greater adaptability and can be automated through computer technology. If a particular module does not meet specific requirements, designers can adjust it at any time until they achieve the desired results. As a result, modular design is often viewed as an innovative approach that aligns well with the concept of mass customization in the fashion industry.

A complete design style includes *Basic Style, Details*, and *Accessories*. For instance, in the design of women's swimwear, the basic style comprises components such as *Pattern*, chest level, and waist l*evel*, each of which can take on different values from a set of style elements. For example, the pattern value can be chosen from the set of options $\{Traditional, Ruffled, One\ shoulder, Strapless\}$. *Details* comprise the detailed components, i.e., $Bra\ type, Bra\ padding, Brook\ type, and\ Print\ type$. The detail component involves selecting one value from a few detail elements. For example, the *Bra type* value is chosen from a component from $\{Push\ up, Triangle\}$. A complete design style is formed by combining one basic style with detail elements selected from the four detail components, as shown in $Garment\ Style =< Basic\ Style, Details\ >$. All design styles form a design style base. Descriptions of all the elements and their symbols are listed in Table 1. Elements can be added, removed, or updated following new fashion trends and user preferences.

Table 1. Style, detail, accessory, and their symbols.

Basic style components	**Basic style elements**	**Symbol**	**Detail component**	**Detail element**	**Symbol**
PATTERN	Traditional	*PATTERN1 (D1)*	Bra type (Detail 1)	Push Up	D11
	Ruffled	*PATTERN2 (D2)*		Triangle	D12
	One shoulder	*PATTERN3 (D3)*	Bra padding (Detail 2)	Removable pad	D13
	Strapless	*PATTERN4 (D4)*		No removable pad	D14
				No pad	D15
BUST LEVEL	Natural	*BUST LEVEL1 (D5)*	Brook type (Detail 3)	Ribbon	D16
	V neck	*BUST LEVEL2*		Cord	D17

		(D6)			
	Pronounced	*BUST LEVEL3 (D7)*		Hook	D18
				Animal print	D19
WAIST LEVEL	Natural	*WAIST LEVEL1 (D8)*	Print type (Detail 4)	Moles	D20
	High Leg	*WAIST LEVEL2 (D9)*		Combined colors	D21
	Thong	*WAIST LEVEL3 (D10)*		Unprinted	D22

In this data collection process, we focus solely on basic style elements to keep things simple, as the details are less dependent on body fit.

Let $PATTERN = \{PATTERN_1, PATTERN_2, \ldots, PATTERN_{k_1}\}$ be the set of Pattern elements. As only one pattern is selected for each garment design (in this case, it is a swimwear), we use a pattern vector, i.e. $pattern = (pattern_1, pattern_2, \ldots, pattern_{k_1})$ in the following calculation presented in Eq. 5, we have

$$pattern_i = \begin{cases} 1, & if\ thepattern\ PATTERN_i\ is\ selected \\ 0, & otherwise \end{cases} \qquad i = 1,2,\ldots,k_1. \tag{5}$$

Let $BUST = \{BUST_1, BUST_2, \ldots, BUST_{k_3}\}$be the set of Bust-level elements. As only one bust-level is selected for each garment design (in this case, it is a swimwear), we use a bust-level vector, i.e. $bust = (bust_1, bust_2, \ldots,_{k_3})$ in the following calculation presented in Eq. 6, we have

$$bust_i = \begin{cases} 1, & if\ thebust-level\ BUST_i\ is\ selected \\ 0, & otherwise \end{cases} \qquad i = 1,2,\ldots,k_3. \tag{6}$$

Let $WAIST = \{WAIST_1, WAIST_2, \ldots, WAIST_{k_2}\}$be the set of Waist-level elements. As only one waist-level is selected for each garment design (in this case, it is a swimwear), we use a waist-level vector, i.e. $waist = (waist_1, waist_2, \ldots, waist_{k_2})$ in the following calculation presented in Eq. 7, we have

$$waist_i = \begin{cases} 1, & if\ thewaist-level\ WAIST_i\ is\ selected \\ 0, & otherwise \end{cases} \qquad i = 1,2,\ldots,k_2. \tag{7}$$

Let $DETAIL = \{DETAIL_1, DETAIL_2, \ldots, DETAIL_{\mu_1}\}$be the set of all the $\mu_1$detail components. There are $n_i$elements in each detail component $DETAIL_i$ $(i \in \{1,2,\ldots,\mu_1\})$, denoted as $DETAIL_{i1}, DETAIL_{i2}, \ldots, DETAIL_{in_i}$. As only one element is selected for each detail component, we use $\mu_1$detail component vectors, i.e., $d^{(i)} = (detail_{i1}, detail_{i2}, \ldots, detail_{in_i})$ $(i = 1,2,\ldots,\mu_1)$ in the following calculation presented in Eq. 8, we have

$$detail_{ij} = \begin{cases} 1, & if\ the\ detail\ element\ DETAIL_{ij_i}\ is\ selected \\ 0, & otherwise \end{cases} \qquad i = 1,2,\ldots,\mu_1; \quad j = 1,2,\ldots,n_i \tag{8}$$

denote$k_4 = \sum_{i=1}^{\mu_1} n_i$which means the total number of all possible detail elements, and $K = k_1 + k_2 + k_3 + k_4$, the total number of all possible design style elements.

Let $s = PATTERN_x, BUST_y, WAIST_z, DETAIL_{1i_1}, \dots, DETAIL_{\mu_1 i_{\mu_1}})$ be a specific style vector, and all style vectors constitute a set of design style *S*, obtained by combining all style components.

Denote $\mu = 3 + \mu_1$,meaning the total number of all style elements in a specific design style.
Let a block matrix STYLE, presented in Eq. 9, be the style matrix, where:

$$STYLE = \begin{bmatrix} pattern & 0 & 0 & 0 & 0 & 0 \\ 0 & bust & 0 & 0 & 0 & 0 \\ 0 & 0 & waist & 0 & 0 & 0 \\ 0 & 0 & 0 & d^{(1)} & 0 & 0 \\ 0 & 0 & 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & 0 & 0 & d^{(\mu_1)} \end{bmatrix}_{\mu \times K} \quad (9)$$

Let $T = \{T_1, T_2, \dots, T_t\}$be the set of *t* fashion themes.

3.1.4 Fashion themes

The fashion themes included in this study are "Neuter-Feminine (T_1)". "Elegant-Wild (T_2)", and "Traditional-Modern (T_3)". They use a scale of seven points (-3, -2, -1, 0, 1, 2, 3). For example, the qualitative scale of evaluation for the fashion theme "Elegant-Wild" is as follows {extreme elegant (-3), elegant (-2), a little elegant (-1), neutral (0), a little wild (1), wild (2), extreme wild (3)}.

3.2 Expert panel composition

The data collection process focused solely on essential colors and design style elements, prioritizing simplicity in our approach, as finer details are less influenced by fashion themes. It engaged two groups of panelists whose main task was to evaluate whether the style elements (colors) harmonized with a specific fashion theme. Ten panelists participated in the sensory data collection process conducted in this study. Two groups were formed. Each group had five panelists. They were selected based on their expertise in fashion design and garment evaluation, making them suitable for assessing the relationship between a fashion theme and a specific color (Group 1) and the relationship between a fashion theme and design styles (Group 2). The main characteristics of the panelists were as follows:

- All panelists were professionals with experience in fashion design,
- The panelists were selected for their diverse aesthetic viewpoints,
- The panelists accepted and were trained in sensory evaluation techniques,
- The panelists accepted and underwent a one-hour training session that involved recognizing fashion themes through images, exploring color and design styles through in-depth interviews and visual aids, and participating in sensory evaluation training, which included visual experiences to refine their observational skills for evaluating how well swimsuit styles fit various fashion themes.

Their professional backgrounds and training in both garment design and sensory evaluation enabled the panelists to assess fit in a nuanced way that incorporated both technical garment fitting and subjective visual impressions. Given their diverse perspectives on body aesthetics, the panelists could offer a more comprehensive understanding of how different swimsuit styles suit various fashion themes and personal preferences. The structured training session and transparent evaluation criteria ensured that the panelists consistently assessed the swimsuits according to the same standards, allowing reliable and reproducible results.

3.3 Data Collection for Fashion Themes and Colors

3.3.1 Data collection design

This design examined the relationship between fashion themes and color elements, specifically hue, value, and chroma. It was structured to capture the subjective assessments of the expert panelists regarding the association between different colors and specific fashion themes. The objective of this design was to quantify the relevance of various color elements to a set of fashion themes. The expert panelists analyzed different fashion themes and color samples. For this, the expert panelists assess how well each color aligns with the theme. Here, the expert panelists used a seven-point linguistic scale.

3.3.2 Data collection and scoring

The data collection process was designed to ensure expert evaluations were captured and formalized into fuzzy data. The scale used by the experts was as follows: {-3: Very Irrelevant, -2: Irrelevant, -1: Slightly Irrelevant, 0: Neutral, +1: Slightly Relevant, +2: Relevant, +3: Very Relevant}. The scores were recorded in a homogeneous format and then converted into fuzzy numbers. Each score was represented as a fuzzy set. The membership functions were defined according to the linguistic terms used by the experts.

3.4 Data Collection for Fashion Themes and Design Styles

3.4.1 Data collection design

This design explored the relationship between fashion themes and design styles. The design styles included patterns, waist-level, and bust designs. This data collection design was similar to the first but focused on style elements rather than colors. The objective was to assess the relevancy of different design styles to specific fashion themes using fuzzy logic. The expert panelists were presented with a series of fashion themes, illustrations, or samples of varying design styles. These styles included variations in garment structure, patterns, and details relevant to the context of women's swimwear. The expert panelists evaluated the relevance of each design style to the fashion themes using the same linguistic scale as described in Section 3.3 for data collection.

3.4.2 Data collection and scoring

The data collection process is conducted in the same manner as described in Section 3.3, with adjustments made to accommodate the distinct nature of the design elements being evaluated. The experts used the same fuzzy linguistic scale (-3 to +3) to score the relevancy of design styles to the fashion themes. The scoring system was designed to capture the subjective opinions of the experts in a quantifiable form. The evaluations were recorded and transformed into fuzzy numbers. After that, they are used to represent the relevancy between each style and the fashion themes.

4 Proposed fuzzy modeling framework

In this section, we introduce a fuzzy modeling framework designed to formalize the relationships between fashion themes, colors, and styles, particularly in the context of women's swimwear design. This framework utilizes fuzzy logic to manage the inherent ambiguity in fashion design decisions, allowing designers to quantify and structure the complex relationships between design elements. The framework is built using fuzzy sets and membership functions, with expert evaluations used to establish fuzzy relational matrices. These matrices capture how different color and style elements align with various fashion themes. The modeling process includes defining linguistic variables, applying fuzzy logic operations, and defuzzifying the results to provide actionable design insights. By structuring the relationship between fashion themes, colors, and styles, this framework offers a systematic approach to decision-making, supporting more personalized and consistent garment design in the competitive fashion industry.

4.1 Modeling the relationship between fashion themes and colors

This subsection uses fuzzy techniques to build relational models between fashion themes and colors. Figure 1 shows the flow diagram of the proposed models, and the modeling details are given below.

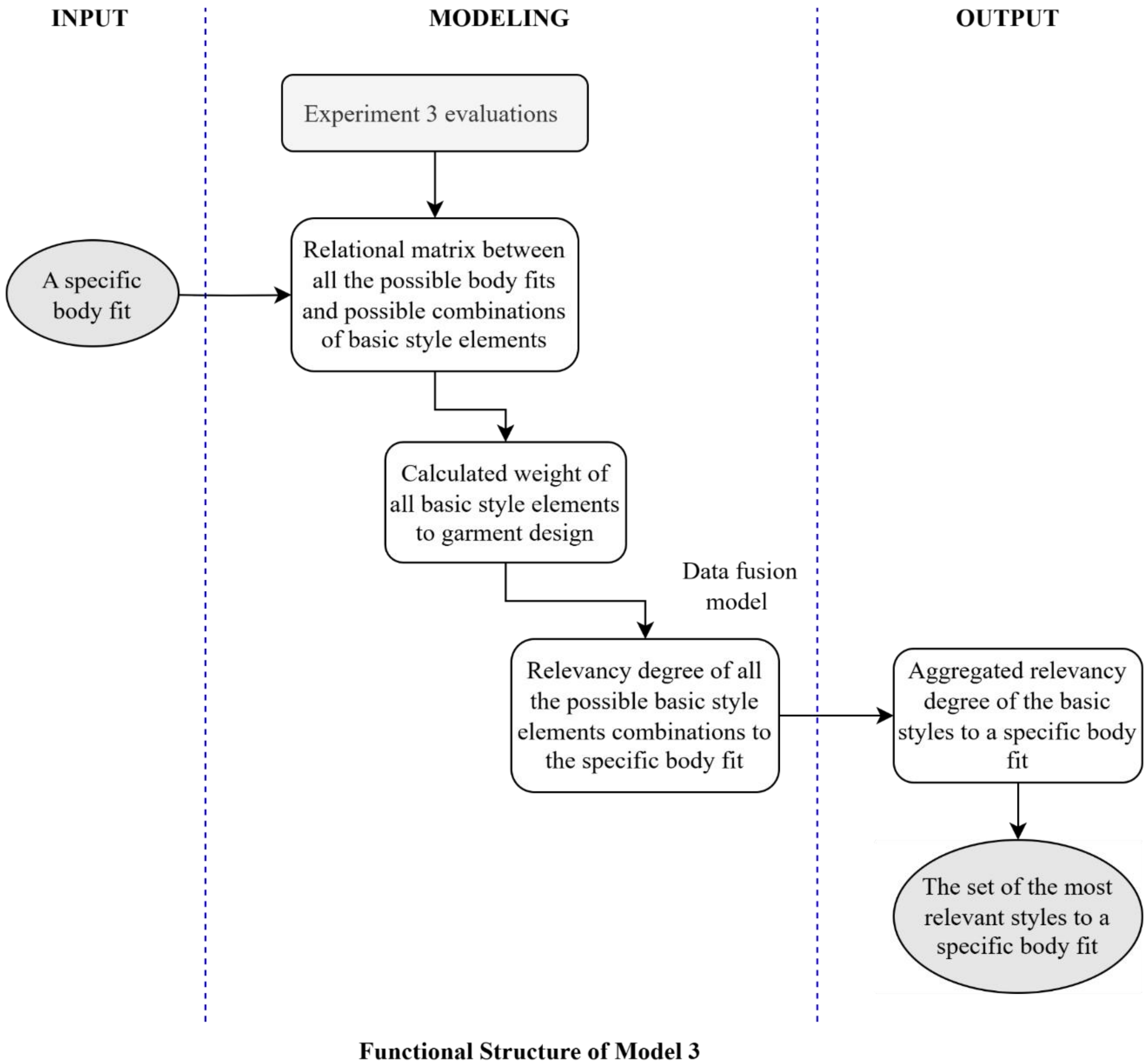

Fig. 1. Flow diagram of the functional structure of the proposed model.

Section 3 uses a linguistic set of {Very Irrelevant, Irrelevant, Slightly Irrelevant, Neutral, Slightly Relevant, Relevant, Very Relevant} to evaluate scores. These seven categories are expressed respectively by seven fuzzy sets$\tilde{A}_{-3}, \tilde{A}_{-2}, \tilde{A}_{-1}, \tilde{A}_{0}, \tilde{A}_{1}, \tilde{A}_{2}, \tilde{A}_{3}$, which have the property of "bilateral symmetry and middle value is higher than bilateral ones." These seven sets are considered standard evaluation scores in our computations. We assume that "very irrelevant," "irrelevant," "slightly relevant," "neutral," "slightly relevant," "relevant," and "very relevant" are expressed respectively by "-3", "-2", "-1" "0", "1", "2" and "3". Using seven "middle type" membership functions$\mu_{\tilde{A}_k}(x)$, $(k = -3, -2 - 1, 0, 1, 2, 3)$ defined on the interval [-3, 3], and presented in Eq. 10, we can express these seven fuzzy sets. They must follow the conditions below and be in the same coordination system.

The peaks of the seven membership functions are located at the points (-3, 1), (-2, 1), and (-1, 1), (0, 1), (1, 1), (2, 1), (3, 1). If one of the values is 1, the other six will be 0. The intersection of two adjacent membership functions corresponds to a value of 0.5 on the ordinate axis, representing the maximum level of fuzziness. We suggest using seven triangular membership functions designed to simplify the process.

$$\mu_{\tilde{A}_k}(x) = \begin{cases} x - k + 1 & if \quad max\{-3, k - 1\} \le x \le k \\ -x + k + 1 & if \quad k \le x \le min\{3, k + 1\} \\ 0 & otherwise \end{cases} \quad , k = -3, -2 - 1, 0, 1, 2, 3 \tag{10}$$

They are shown in Figure 2.

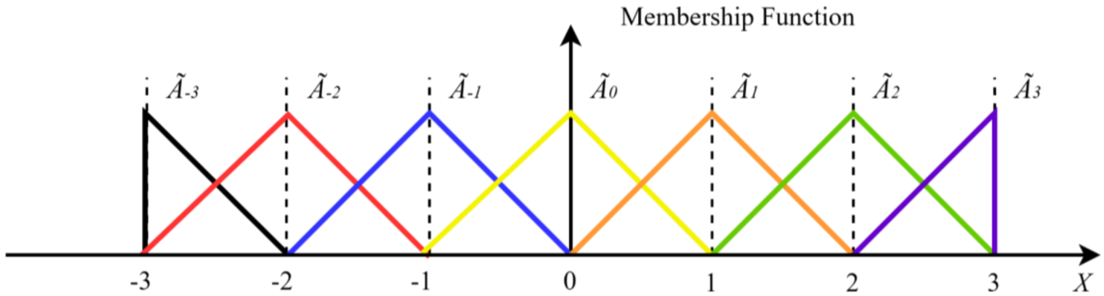

Fig. 2. The seven membership functions of evaluation scores on the relevancy of colors to fashion themes. $\mu_{\tilde{A}_k}(x),\ (k = -3, -2, -1, 0, 1, 2, 3)$

We assume that for a given set of r panelists, $r_{ij}^{(k)}$ represents the number of people among the r panelists who give the evaluation score k ($k \in \{-3, -2, -1, 0, 1, 2, 3\}$) on the relevancy of the *i-th* ($i \in \{1, 2, \dots, v\}$) color element. The set of all the v possible color elements is: $C = \{\overset{low}{HUE_1}, \overset{middle}{HUE_2}, \overset{high}{HUE_3}, \overset{low}{VALUE_1}, \overset{middle}{VALUE_2}, \overset{high}{VALUE_3}, \overset{low}{CHROMA_1}, \overset{middle}{CHROMA_2}, \overset{high}{CHROMA_3}\}$ ($v = 9$) to the *j*-th ($j \in \{1, 2, \dots, t\}$) fashion theme (t is the total number of all the fashion themes) ($t = 3$). The set of all the t fashion themes is $T = \{\overset{T_1}{Neuter - Feminine}, \overset{T_2}{Elegant - Wild}, \overset{T_3}{Traditional - Modern}\}$.

A fuzzy distribution can express the evaluation results of all the panelist as shown in Eq. 11:

$$\tilde{E}_{ij} = \left(\frac{r_{ij}^{(-3)}}{r}, \frac{r_{ij}^{(-2)}}{r}, \frac{r_{ij}^{(-1)}}{r}, \frac{r_{ij}^{(0)}}{r}, \frac{r_{ij}^{(1)}}{r}, \frac{r_{ij}^{(2)}}{r}, \frac{r_{ij}^{(3)}}{r}\right) = \left(e_{ij}^{(-3)}, e_{ij}^{(-2)}, e_{ij}^{(-1)}, e_{ij}^{(0)}, e_{ij}^{(1)}, e_{ij}^{(2)}, e_{ij}^{(3)}\right) \quad \textbf{(11)}$$

where $e_{ij}^{(-3)} + e_{ij}^{(-2)} + e_{ij}^{(-1)} + e_{ij}^{(0)} + e_{ij}^{(1)} + e_{ij}^{(2)} + e_{ij}^{(3)} = 1$.

$\tilde{E}_{ij}$ is a fuzzy set, whose membership function $\mu_{\tilde{E}_{ij}}(x)$ is a triangle or a polygonal function which takes the points (-3,0), (-3, $e_{ij}^{(-3)}$), (-2, $e_{ij}^{(-2)}$), (-1, $e_{ij}^{(-1)}$), (0, $e_{ij}^{(0)}$), (1, $e_{ij}^{(1)}$), (2, $e_{ij}^{(2)}$),(3, $e_{ij}^{(3)}$), (3,0) as vertexes (some point could be coincident).

A general membership function of the evaluation results is given in Figure 3.

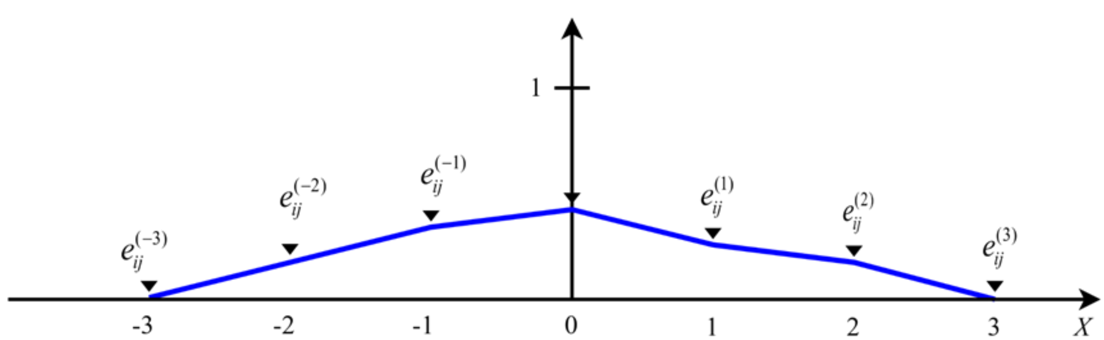

Fig. 3. A general fuzzy membership function of the evaluation results.

The membership function of a fuzzy distribution set uses the formula shown in Eq. 12 for its construction:

$$\mu_{A\cup B}(x) = min(1, \mu_A(x) + \mu_B(x)) \tag{12}$$

We define the *Close Degree* (Dong et al., 2020) of the distribution of evaluation data $\tilde{E}_{ij}$ on the *i-th* color element related to the *j-th* fashion theme (T_j), denoted as $r(\tilde{E}_{ij}, \tilde{A}_k)$ to the previously defined standard evaluation levels (scores) $\tilde{A}_k$ according to Eq. 13.

$$r(\tilde{E}_{ij}, \tilde{A}_k) = \frac{\int_{-1}^{1}\left[\mu_{\tilde{E}_{ij}}(x) \wedge \mu_{\tilde{A}_k}(x)\right]dx}{\int_{-1}^{1}\left[\mu_{\tilde{E}_{ij}}(x) \vee \mu_{\tilde{A}_k}(x)\right]dx},\ i = 1,2,\ldots,27, j = 1,2,3, k = -3,-2,-1,0,1,2,3 \tag{13}$$

Evidently $r(\tilde{E}_{ij}, \tilde{A}_k)$ is larger if $\tilde{E}_{ij}$ is closer to $\tilde{A}_k$. $r(\tilde{E}_{ij}, \tilde{A}_k)$ satisfies the following three properties for all close degrees:

i) $0 \leq r(\tilde{E}_{ij}, \tilde{A}_k) \leq 1$, and $r(\tilde{E}_{ij}, \tilde{A}_k) = 1 \quad \Leftrightarrow \quad \tilde{E}_{ij} = \tilde{A}_k$,
ii) $r(\tilde{E}_{ij}, \tilde{A}_k) = r(\tilde{A}_k, \tilde{E}_{ij})$,
iii) $r(\tilde{E}_{ij}, \tilde{A}_k) \leq r(\tilde{E}_{ij}, \tilde{C}) + r(\tilde{C}, \tilde{A}_k)$, $\tilde{C}$ is a fuzzy set defined on [-3,3].

The $(v \times 7)$-dimensional relational matrix of all the possible color elements C to the fashion theme T_j for all the evaluation levels is defined by Eq. 14.

$$R(C, T_j) = (r(\tilde{E}_{ij}, \tilde{A}_k))_{v\times 7} \quad , \quad j = 1,2,\ldots,t. \tag{14}$$

where v is the total number of all the colors elements.
The (3x7)-dimensional relational matrix $R(c, T_j)$ of a specific color c (composed of 3 color elements) to the fashion theme T_j is defined by Eq.. 15.

$$R(c, T_j) = COLOR_{3\times v} \circ R(C, T_j)_{v\times 7} \tag{15}$$

Assume the weights of three-color properties (Hue, Value, and Chroma) are w_1, w_2, and w_3, which constitute a weight vector $w = (w_1, w_2, w_3)$.
The *relevancy degree* of a specific color c to the *k-th* evaluation level of fashion theme T_j is defined by Eq. 16.

$$\rho(c, T_j^{(k)}) = w \circ R(c, T_j)^{(k)} \tag{16}$$

where $T_j^{(k)}$ expresses the *k-th* evaluation level of the fashion theme T_j and $R(c, T_j)^{(k)}$ the *k-th* vector of $R(c, T_j)$, $1 \leq k \leq 7$.
Thus, we obtain the distribution of the relevancy degrees of a specific color c related to the fashion theme T_j for all the evaluation levels all as shown in Eq. 17.

$$CT^{(j)} = \left(\frac{\rho(c, T_j^{(1)}}{\sum_{k=1}^{7}\rho(c, T_j^{(k)})}, \frac{\rho(c, T_j^{(2)}}{\sum_{k=1}^{7}\rho(c, T_j^{(k)})}, \ldots, \frac{\rho(c, T_j^{(7)}}{\sum_{k=1}^{7}\rho(c, T_j^{(k)})}\right) \tag{17}$$

According to the fuzzy selecting near principle (Dong et al., 2020), c is the most relevant color to the k^* *-th* evaluation level of the fashion theme T_j, if fulfill Eq. 18.

$$\rho(c, T_j^{(k^*)}) = \vee_{k=1}^{7} \{\rho(c, T_j^{(k)})\} \quad \textbf{(18)}$$

For a given evaluation level (k^* *-th* level) of the fashion theme T_j, all the colors satisfying the above Equation (i.e. their distribution of relevancy degrees related to T_j reach the maximums at the k^* *-th* evaluation level) constitute the set of colors $C_{k^*}^{(j)}$.
If several fashion themes are considered, we can obtain the most relevant set of colors for each evaluation level of a specific theme. We just take the intersection of their corresponding sets of colors as the final set of colors.

The defuzzified relevance scores emphasize the colors that are most strongly associated with each theme. The findings clearly connect the fashion themes and the chosen color palettes. The fuzzy model captures the subtle details in expert assessments, offering a systematic method for selecting colors in garment design.

4.2 Modeling the relationship between fashion themes and basic style elements

In this subsection, we set up the relational model between fashion themes and design styles using fuzzy techniques. The flow diagram of the model is shown in Figure 4.

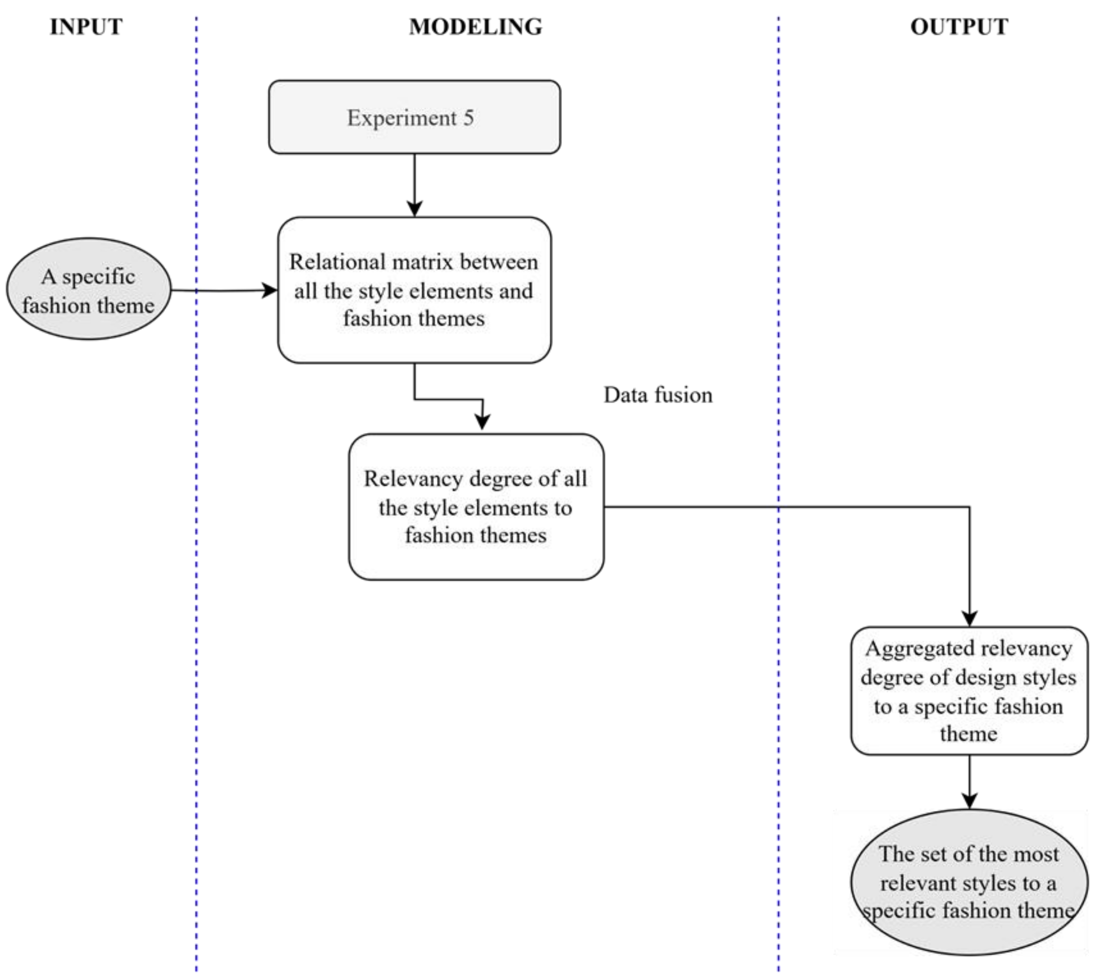

Fig. 4. Flow diagram of the functional structure of the proposed model on the relationship between fashion themes and basic style elements.

Section 3 uses a linguistic set of {Very Irrelevant, Irrelevant, Slightly Irrelevant, Neutral, Slightly Relevant, Relevant, Very Relevant} to evaluate scores. These seven categories are expressed respectively by seven fuzzy sets $\tilde{A}_{-3}, \tilde{A}_{-2}, \tilde{A}_{-1}, \tilde{A}_0, \tilde{A}_1, \tilde{A}_2, \tilde{A}_3$, which have the property of "bilateral symmetry and middle value is higher than bilateral ones." These seven sets are considered standard evaluation scores in our computations. We assume that "very irrelevant," "irrelevant," "slightly relevant," "neutral," "slightly relevant," "relevant," and "very relevant" are expressed respectively by "-3", "-2", "-1," "0", "1", "2" and "3". Using seven "middle type" membership functions$\mu_{\tilde{A}_k}(x)$, $(k = -3, -2 - 1,0,1,2,3)$ defined on the interval [-3, 3], we can express these seven fuzzy sets. They must follow the conditions below and be in the same coordination system.

The peaks of the seven membership functions are located at the points (-3, 1), (-2, 1), and (-1, 1), (0, 1), (1, 1), (2, 1), (3, 1). If one of the values is 1, the other six will be 0. The intersection of two adjacent membership functions corresponds to a value of 0.5 on the ordinate axis, representing the maximum level of fuzziness. We suggest using seven triangular membership functions, designed in the same form as Eq. 10, as shown in Figure 2. We assume that for a given set of *r* panelists, $r_{ij}^{(k)}$represents the number of people among the *r* panelists who give the evaluation score *k* $(k \in \{-3, -2, -1,0,1,2,3\})$ on the relevancy of the *i-th* $(i \in \{1,2, \dots, K\})$ style element. Table 1 in Section 3 presents the set of all possible basic style elements. (*K* = 10) to the *j*-th $(j \in \{1,2, \dots, t\})$ fashion theme (*t* is the total number of all the fashion themes) (*t* = 3). The set of all the *t* fashion themes is $T = \{\overset{T_1}{Sport - Contemporary}, \overset{T_2}{Elegant - Wild}, \overset{T_3}{Traditional - Modern}\}$.

A fuzzy distribution $\tilde{E}_{ij}$can express the evaluation results of all the panelists in the same form as equation (11). $\tilde{E}_{ij}$is a fuzzy set whose membership function $\mu_{\tilde{E}_{ij}}(x)$ is a triangle or a polygonal function that takes the points (-3,0), (-3, $e_{ij}^{(-3)}$), (-2, $e_{ij}^{(-2)}$), (-1, $e_{ij}^{(-1)}$), (0, $e_{ij}^{(0)}$), (1, $e_{ij}^{(1)}$), (2, $e_{ij}^{(2)}$),(3, $e_{ij}^{(3)}$), (3,0) as vertexes (some point could be coincident). A general membership function of the evaluation results is given in the same form as Figure 3. The membership function of a fuzzy distribution set uses the formula (12) for its construction:
We define the *Close Degree* (Dong et al., 2020) of the distribution of evaluation data$\tilde{E}_{ij}$on the *i-th* basic style element related to the *j-th* fashion theme (T_j), denoted as $r(\tilde{E}_{ij}, \tilde{A}_k)$ to the previously defined standard evaluation levels (scores)$\tilde{A}_k$according to Equation (13).

The $(K \times 7)$-dimensional relational matrix of all the possible basic style elements *S* to the fashion theme T_j for all the evaluation levels is defined by Eq. 19.

$$R(S, T_j) = (r(\tilde{E}_{ij}, \tilde{A}_k))_{K \times 7} \quad , \quad j = 1,2, \dots, t \tag{19}$$

where *K*(=10) is the total number of all the basic style elements.
The $(\mu \times 7)$-dimensional relational matrix $R(s, T_j)$ of a specific basic style *s* (composed of 10 basic style elements) to the fashion theme T_j is defined by Eq. 20.

$$R(s, T_j)_{\mu \times 7} = STYLE_{\mu \times K} \circ R(S, T_j)_{K \times 7}, \quad j = 1,2, \dots, 7 \tag{20}$$

Assume the weights of the style elements are$w_1, w_2, \dots w_\mu$, which constitute a weight vector $w = (w_1, w_2, \dots, w_\mu)$, and μ is the total number of all style elements in the specific style *s*.
The *relevancy degree* of a specific style *s* to the *k-th* evaluation level of a fashion theme T_j is defined by Eq. 21.

$$\rho(s, T_j^{(k)}) = w \circ R(s, T_j)^{(k)} \tag{21}$$

where$T_j^{(k)}$expresses the *k-th* evaluation level of the fashion themeT_j and$R(s, T_j)^{(k)}$the *k-th* vector of$R(s, T_j)$, $1 \leq k \leq 7$.
Thus, we obtain the distribution of the relevancy degrees of a specific style *s* related to the fashion theme T_j for all the evaluation levels as shown in Eq. 22.

$$\rho(s, T_j^{(k^*)}) = \vee_{k=1}^{7} \{\rho(s, T_j^{(k)})\} \tag{22}$$

For a given evaluation level (k^* *-th* level) of the fashion theme T_j, all the colors satisfying the above Equation (i.e. their distribution of relevancy degrees related toT_j reach the maximums at the k^* *-th* evaluation level) constitute the set of styles $S_{k^*}^{(j)}$.

If several fashion themes are considered, we can obtain the most relevant set of styles for each evaluation level of a specific theme. We just take the intersection of their corresponding sets of styles as the final set of styles. We can suggest which evaluation level of relevance a new style belongs to for a specific fashion theme. In practice, the base of styles is an open structure that permits designers to integrate more new styles. With more styles, the recommendation results will become more reasonable.

The fuzzy modeling framework models the relationships between fashion themes and design styles. It prioritizes style elements for each theme and shows a strong connection between certain design styles and fashion themes. The fuzzy models formalize expert assessments and provide practical insights for creating thematic garment collections.

5 Experimentation

In this section, we present the experimentation process designed to validate the fuzzy modeling framework developed to capture the relationships between fashion themes, colors, and design styles in women's swimwear. The experiments were structured to assess how effectively fuzzy models reflect expert perceptions of the relevance of color and style to various fashion themes. Through two main experiments, we evaluated the alignment of color elements (hue, value, and chroma) and basic design styles with specific fashion themes. The results of these experiments provide critical insights into the accuracy and practical relevance of the fuzzy models, ensuring that the proposed approach can support more informed and consistent decision-making in garment design.

5.1 Validation of the modeling of the relationship between fashion themes and colors

To measure the effectiveness of the fuzzy model in examining the relationship between fashion themes and colors, an evaluation involving ten panelists was conducted. Each panelist rated the relevance of each color to three fashion themes: Sport-Contemporary (T_1), Elegant-Wild (T_2), and Traditional-Modern (T_3), using a linguistic scale { -3: Very Irrelevant, -2: Irrelevant, -1: Slightly Irrelevant, 0: Neutral, +1: Slightly Relevant, +2: Relevant, +3: Very Relevant}. The panelists reviewed visual representations that showcased appropriate combinations of 27 women's swimsuits in various colors. To simplify the process, the linguistic score with the highest number of selections among the ten panelists was designated as the final result for each evaluation; in cases where two or more scores were tied, one was chosen randomly. This procedure aims to ensure that the final assessments closely reflect collective preferences.

Tables 2, 3, and 4 display the expert panelists' perceptions regarding the significance of color in swimsuits in relation to fashion themes. Table 5 presents the values of the model's output results and panelists' perceptions of the relationship between colors and fashion themes. Figure 5 offers a detailed comparison between the model's outputs and the panelists' evaluations, concentrating on 27 swimsuits in various colors. This analysis specifically examines the connection between fashion themes and the colors of swimsuits.

Table 2. Expert panelists' perceptions of the relevance of color in swimsuits to the fashion theme: Traditional - Modern

Colors	Very Irrelevant	Irrelevant	Slightly Irrelevant	Neutral	Slightly Relevant	Relevant	Very Relevant
1	0	0	0	2	0	2	6
2	0	1	3	4	0	2	0
3	2	3	1	2	0	2	0
4	1	2	2	1	1	2	1
5	0	6	2	0	0	1	1
6	0	0	0	1	0	0	9
7	0	0	0	0	0	6	4
8	0	0	1	1	4	1	3
9	3	2	0	0	1	1	3
10	0	2	2	4	0	2	0
11	0	0	2	2	1	3	2
12	0	0	0	1	2	3	4
13	1	3	2	2	1	0	1
14	5	0	0	2	1	1	1
15	2	3	0	4	1	0	0
16	6	2	0	2	0	0	0
17	4	1	0	3	1	1	0
18	0	1	0	0	0	5	4
19	0	1	0	2	3	2	2
20	2	0	4	2	1	1	0
21	0	0	0	4	1	2	3

22	0	0	1	0	0	3	6
23	0	3	0	1	4	1	1
24	0	0	0	0	0	2	8
25	0	2	2	5	0	1	0
26	0	1	0	4	0	5	0
27	3	4	1	2	0	0	0

Table 3. Expert panelists' perceptions of the relevance of color in swimsuits to the fashion theme: Sport - Contemporary

Colors	Very Irrelevant	Irrelevant	Slightly Irrelevant	Neutral	Slightly Relevant	Relevant	Very Relevant
1	0	1	5	3	1	0	0
2	1	0	0	1	5	1	2
3	2	2	2	1	1	2	0
4	2	3	0	2	1	2	0
5	1	0	0	0	0	4	5
6	1	3	2	2	1	0	1
7	0	2	0	3	1	3	1
8	0	1	3	6	0	0	0
9	0	1	0	1	3	0	5
10	0	0	0	4	0	2	4
11	0	0	1	4	0	2	3
12	1	1	2	3	1	1	1
13	0	0	2	2	3	3	0
14	0	1	0	1	1	3	4
15	4	1	1	0	2	1	1
16	1	1	1	6	1	0	0
17	0	0	3	3	1	2	1
18	1	0	0	4	1	2	2
19	0	0	2	5	2	0	1
20	1	0	0	3	1	4	1
21	1	0	1	1	3	3	1
22	0	1	0	4	4	1	0
23	0	2	2	2	1	3	0
24	4	2	1	2	1	0	0
25	0	4	1	3	0	2	0
26	2	1	2	1	0	3	1
27	0	0	0	4	2	4	0

Table 4. Expert panelists' perceptions of the relevance of color in swimsuits to the fashion theme: Elegant - Wild

Colors	Very Irrelevant	Irrelevant	Slightly Irrelevant	Neutral	Slightly Relevant	Relevant	Very Relevant
1	0	1	4	0	2	2	1
2	1	2	4	1	0	2	0
3	1	4	4	1	0	0	0
4	0	1	5	2	2	0	0
5	2	5	0	2	0	0	1
6	1	0	1	1	0	1	6
7	0	0	2	1	0	5	2
8	0	1	1	0	2	2	4
9	0	2	2	0	0	5	1
10	0	3	3	1	2	1	0
11	0	1	3	2	2	2	0
12	0	0	1	2	1	5	1
13	1	1	2	3	1	1	1
14	3	4	2	1	0	0	0
15	3	2	0	4	1	0	0
16	3	0	1	4	0	1	1
17	3	1	0	6	0	0	0
18	0	1	2	2	2	3	0
19	0	1	1	6	1	1	0
20	1	2	1	2	2	1	1
21	0	0	2	1	0	4	3
22	0	1	0	2	2	1	4
23	0	1	1	2	2	3	1
24	0	0	1	1	1	1	5
25	0	2	2	2	1	1	1
26	0	1	1	0	5	2	0
27	0	1	2	1	4	2	0

Table 5. Values of the model's output results and panelists' perceptions of the relationship between colors and fashion themes.

	Sport-Contemporary (T_1)		**Elegant-Wild (T_2)**		**Traditional-Modern (T_3)**	
Color	**Panelists' perceptions**	**Model Output**	**Panelists' perceptions**	**Model Output**	**Panelists' perceptions**	**Model Output**
1	-1	-1	-1	-1	3	3
2	1	1	-1	-1	0	0
3	-2	-2	-2	-2	-2	-2
4	-2	-2	-1	-1	-2	-2
5	3	3	-2	-2	-2	-2
6	-2	-2	3	3	3	3
7	2	2	2	2	2	2
8	0	0	3	2	1	1
9	3	3	2	2	-3	-3
10	0	0	-1	-1	0	0
11	0	0	-1	-1	2	2
12	0	0	2	2	3	2
13	1	1	0	0	-2	-2
14	3	3	-2	-2	-3	-3
15	-3	-3	0	0	0	0
16	0	0	0	0	-3	-3
17	0	0	0	0	-3	2
18	0	0	2	1	2	2
19	0	0	0	0	1	1
20	2	2	0	0	-1	-1
21	1	1	2	2	0	0
22	1	1	3	3	3	3
23	2	-3	2	2	1	1
24	-3	-3	3	3	3	3
25	-2	-2	-1	-1	0	0
26	2	2	1	1	1	1
27	0	0	1	1	-2	-2

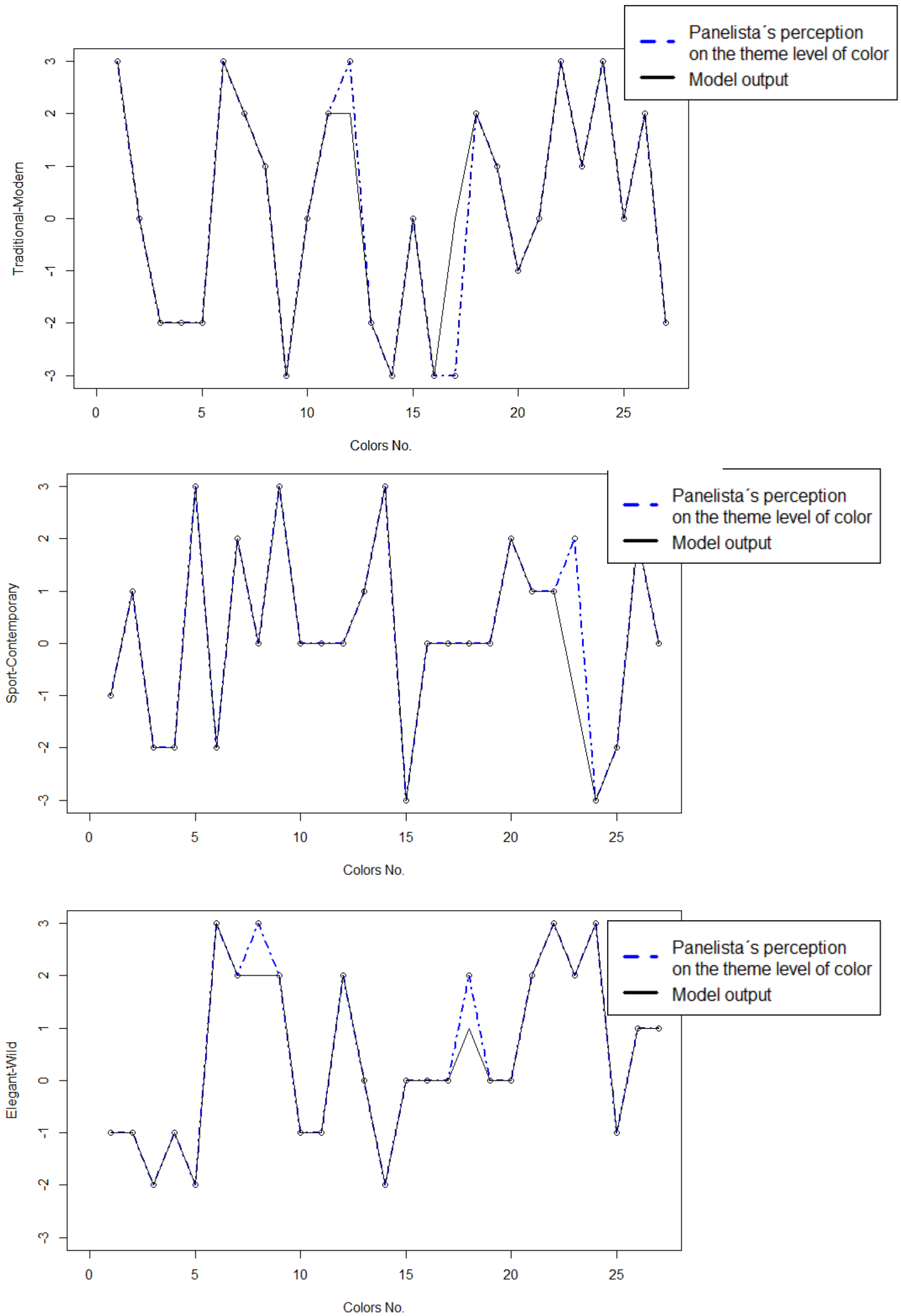

Fig. 5. Comparison of the model's results with the expert's perception of the relevance of colors to fashion themes.

5.2 Validation of the modeling of the relationship between fashion themes and basic styles elements

To assess the effectiveness of the fuzzy model on the relationship between fashion themes and basic style elements, an evaluation involving ten panelists is conducted. Each panelist evaluated the relevance of each design style to three fashion themes (Sport-Contemporary (T_1), Elegant-Wild (T_2), Traditional-Modern (T_3)) using the linguistic scale { -3: Very Irrelevant, -2: Irrelevant, -1: Slightly Irrelevant, 0: Neutral, +1: Slightly Relevant, +2: Relevant, +3: Very Relevant}. The panelists examined visual representations that encapsulated appropriate combinations of 30 typical women's swimsuits of different styles. To streamline the process, the linguistic level of the scale (score) that received the highest number of selections among the ten panelists was designated as the definitive result for each evaluation; in cases where two or more scores were tied, one was chosen randomly. This approach aims to ensure that the final assessments align closely with collective preferences.

Table 6 presents the values of the model's output results and panelists' perceptions of the relationship between styles and fashion themes. Figure 6 presents a detailed comparison between the model's outputs and panelists' evaluations, focusing on 30 swimsuits of different styles. This analysis specifically examines the relationship between fashion themes and styles of swimsuits.

Table 6. Values of the model's output results and panelists' perceptions of the relationship between styles and fashion themes.

	Sport-Contemporary (T_1)		Elegant-Wild (T_2)		Traditional-Modern (T_3)	
Styles	Panelists' perceptions	Model Output	Panelists' perceptions	Model Output	Panelists' perceptions	Model Output
1	1	1	3	3	-1	-3
2	2	2	2	2	2	2
3	2	2	3	3	2	2
4	2	2	3	3	3	3
5	2	2	2	2	-2	-2
6	2	2	3	3	-3	-3
7	2	2	0	0	2	2
8	2	2	0	0	-3	-3
9	-2	-2	0	0	-3	-3
10	1	1	0	0	-3	-3
11	2	2	0	0	2	2
12	-2	-2	0	0	-3	-3
13	1	-2	0	0	-3	-3
14	2	2	0	0	-3	-3
15	2	2	3	3	3	3
16	2	2	3	3	3	3
17	-2	-2	0	0	-3	-3
18	2	2	-1	0	-3	-3
19	2	2	2	2	2	2
20	2	2	2	2	2	2
21	2	2	2	2	2	2
22	2	2	3	3	3	3
23	1	1	0	0	-3	-3
24	2	2	0	0	-3	-3
25	-3	-3	0	0	-3	-3
26	2	2	3	3	2	2
27	-3	-3	0	0	-3	-3
28	-3	-3	0	0	-3	-3
29	2	2	3	3	-3	-3
30	2	2	2	2	2	2

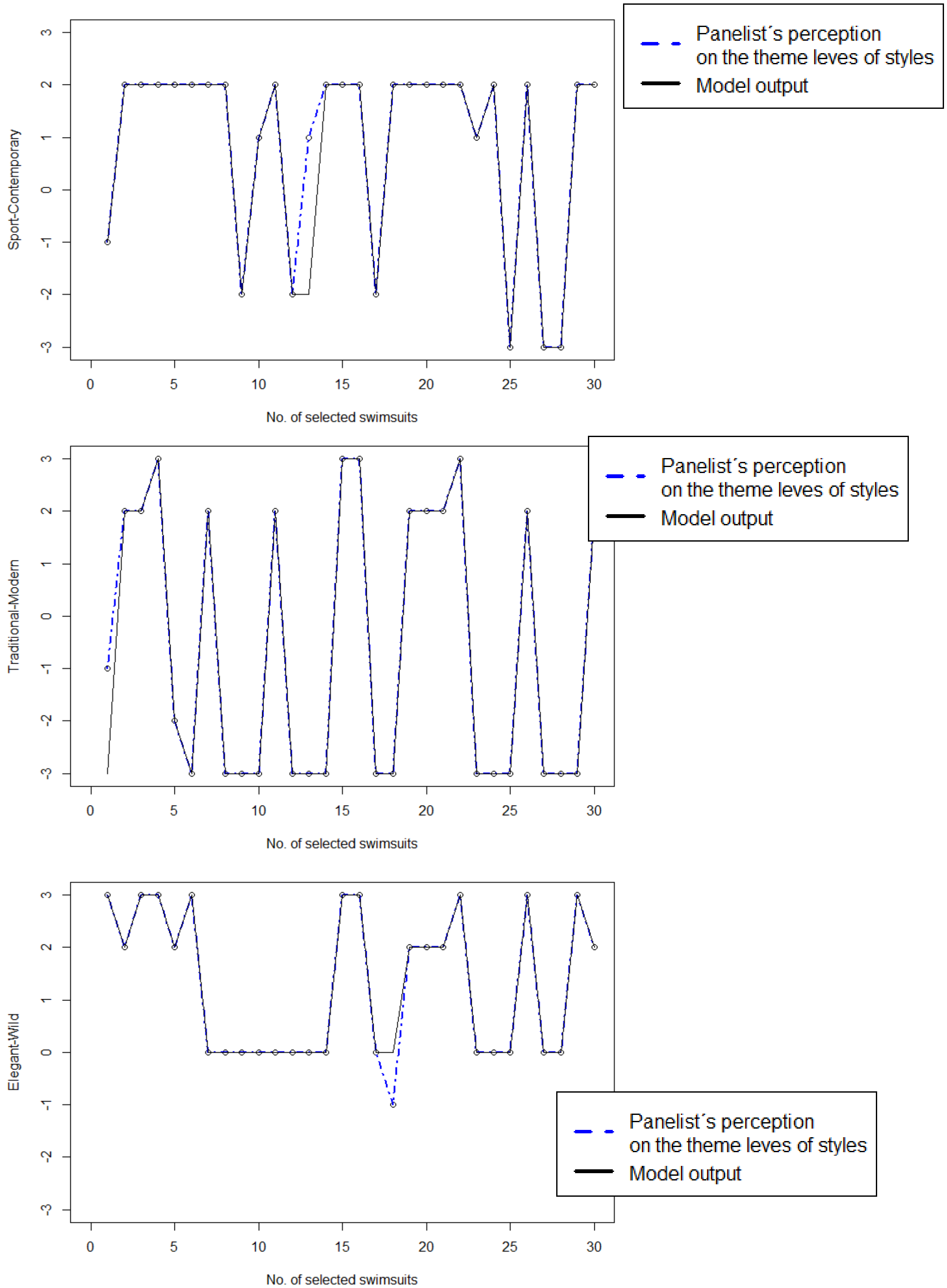

Fig. 6. Comparison of the model's output results with designers' perceptions of the relationship between fashion themes and styles.

Regarding the validation of the model's relationship between fashion themes, colors, and basic style elements, Table 5 (Figures 5) and Table 6 (Figure 6) present the values of the model output and the perception criterion for the various fashion themes, respectively. For each fashion theme, the two set of values appear quite similar, but a more precise analysis is needed to confirm this. The intuitive analysis is not sufficiently accurate, so further validation using a quantitative method is required. For this purpose, we utilize the Root Mean Square Error (*RMSE*) indicator (Chai & Draxler, 2014). It measures the average difference between predicted and actual values in a statistical model. It represents the standard deviation of the residuals, reflecting their dispersion. A lower *RMSE* indicates better model accuracy, as data points align more closely with the regression line. *RMSE* is crucial in predictive modeling, with a value of 0 signifying perfect predictions. Low *RMSE* values imply a good fit and more accurate forecasts, while higher values indicate larger errors. In essence, *RMSE* quantifies how well a model predicts target values by estimating the average deviation from actual values, making it a key performance indicator in assessing prediction quality.

The definition of the *RMSE* formula is as follows. Let the set of all results delivered by the model be $X = \{x_1, x_2, ..., x_n\}$, and let the set of panelists' perceptions be $Y = \{y_1, y_2, ..., y_n\}$. The *RMSE* indicator is defined as shown in Eq. 23.

$$RMSE(X,Y) = \sqrt{\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{n}}, \tag{23}$$

in this equation, all the results $x_i, y_i \in \{-3,-2,-1,0,1,2,3\}$.

6 Results

The results of the fuzzy models were compared with those of the expert panel to validate the accuracy and practical relevance of the fuzzy models. The defuzzified relevancy scores from the fuzzy relational matrices were compared with the qualitative feedback provided by the experts to assess how accurately the fuzzy models reflected their perceptions and identified any discrepancies.

In order to validate the model's relationship between fashion themes and colors, the RMSE values for each fashion theme are presented in Table 7.

Table 7. The *RMSE* indicator of each fashion theme related colors.

Fashion theme	T_1	T_2	T_3
RMSE	0.9622	0.2721	0.9629

Table 7 indicates that the proposed model is acceptable, as all *RMSE* indicator values do not exceed 1, meaning the errors are all below the 1 level of 7 (under 14%) on average. Specifically, the Sport-Contemporary fitting error averages below 1, indicating a deviation of less than 14%, which reflects a high level of accuracy. Moreover, the error associated with the Elegant-Wild fitting remains below 0.3, averaging around 7, corresponding to a deviation of less than 4%. Additionally, the Traditional-Modern fitting exceeds expectations, with an average error of less than 1, resulting in a deviation of less than 14%. These findings highlight the model's effectiveness in accurately fitting the data across this metric

In order to validate the model's relationship between fashion themes and basic style elements, the values of the *RMSE* indicator for all the fashion themes are listed in Table 8.

Table 8. The *RMSE* indicator of each fashion theme related to all the design styles.

Fashion theme	T_1	T_2	T_3
RMSE	0.5477	0.1825	0.3651

Table 8 shows that the proposed model is efficient, as all values of the *RMSE* indicator do not exceed 0.6, indicating that the errors are consistently lower than the 0.6 level of 7, which corresponds to an average error of less than 9%. Specifically, the Sport-Contemporary fitting error averages below 0.6, representing a deviation of less than 9%, which reflects a high level of accuracy. Furthermore, the error associated with the Elegant-Wild level fitting is maintained below 0.2, averaging around 7, which corresponds to a deviation of less than 3%. Additionally, the Traditional-Modern level fitting outperforms expectations, with an average error of less than 0.4, translating to a deviation of less than 6%. These findings underscore the model's effectiveness in accurately fitting the data across this metric. When the proposed model is analyzed, all the error results are less than 0.1. This indicates that the model's output is generally close to the perception criterion. Based on this analysis, the model shows a robust ability to categorize swimsuit styles.

In short, the results of the fuzzy models closely matched the experts' assessments, with only minor discrepancies that fell within acceptable limits and did not significantly affect the models' validity. This indicates that the fuzzy model results are consistent with the expert opinions. It also demonstrates that the fuzzy modeling framework effectively captures the key aspects of fashion design, giving designers greater confidence in the relevancy scores and insights it offers.

These findings are significant for garment designers, particularly those involved in creating customized swimwear on a large scale. The research established a clear and measurable approach to aligning fashion themes with color and style elements. This method helps designers make informed decisions based on expert evaluations, thereby enhancing the consistency and visual appeal of the final products. When designing customized swimwear, it is crucial to align colors and styles with fashion themes to satisfy customer preferences. A fuzzy modeling framework captures expert knowledge to ensure that the final designs fulfill both functional and aesthetic requirements. This can lead to increased customer satisfaction and brand loyalty, as the garments are more likely to resonate with the intended audience.

7 Conclusions and future research

This paper developed a fuzzy modeling framework to explore the relationships between fashion themes, colors, and design styles in women's swimwear. The framework shows a solid procedure for finding relationships between thematic elements and design features and provides a structured method for aligning fashion themes with colors and styles. By means of fuzzy models, the framework effectively captured expert opinions, yielding relevance scores that matched the experts' initial perceptions.

The study offers garment designers a practical tool for making more informed and consistent design decisions, particularly beneficial in mass-customized swimwear. From the methodological point of view, this study expands the application of fuzzy logic in design contexts, demonstrating its utility in modeling subjective relationships. This study uses fuzzy logic to offer useful insights into aligning fashion themes, colors, and design styles in garment design. The framework has the potential to support designers in creating thematically consistent garments that resonate with consumers.

While this study's fuzzy modeling approach offers several advantages, it is also important to acknowledge its strengths and limitations.

Strengths:

- One of the key strengths of the fuzzy modeling framework is its ability to handle the inherent subjectivity in fashion design. Using fuzzy sets and linguistic variables, the framework can capture nuanced expert opinions and translate them into quantifiable data that can be systematically analyzed.
- The fuzzy models are highly adaptable and can be applied to various fashion themes, colors, and styles. This flexibility makes the framework applicable to multiple design contexts beyond swimwear, including other types of garments and even other design industries.
- Aggregating expert evaluations into fuzzy relational matrices helps build a consensus view, which can be particularly valuable in collaborative design environments where multiple stakeholders are involved in the decision-making process.

Limitations:

- Constructing fuzzy relational matrices and the subsequent defuzzification process can be complex and may require specialized knowledge of fuzzy logic. This complexity could be a barrier to adoption for designers unfamiliar with fuzzy techniques.
- The accuracy of the fuzzy models heavily depends on the expert panel's quality and representativeness. If the experts selected do not fully represent the target market or the thematic goals, the relevancy scores generated by the models may be less accurate.
- The fuzzy models could be more tailored to the specific themes, colors, and styles used in the experiments. This could limit the generalizability of the findings to other design contexts or consumer groups.

Future research should explore applying the fuzzy modeling framework to various garments beyond swimwear. This expansion could encompass outerwear, formalwear, and activewear, presenting distinct challenges and opportunities for aligning fashion themes with design elements. Future research could explore creating hybrid models that combine fuzzy logic with other decision-making frameworks, such as multi-criteria decision analysis (MCDA) or artificial intelligence (AI) techniques. These models could provide fashion designers with more versatile tools.

References

Aleem, A., Loureiro, S. M. C., & Bilro, R. G. (2024). Luxury fashion consumption: A review, synthesis and research agenda. *Spanish Journal of Marketing - ESIC*, *28*(2), 144–164. https://doi.org/10.1108/SJME-06-2021-0105

Barnes, L., & Lea-Greenwood, G. (2006). Fast fashioning the supply chain: Shaping the research agenda. *Journal of Fashion Marketing and Management*, *10*(3), 259–271. https://doi.org/10.1108/13612020610679259

Chai, T., & Draxler, R. R. (2014). Root mean square error (RMSE) or mean absolute error (MAE)? – Arguments against avoiding RMSE in the literature. *Geoscientific Model Development*, *7*, 1247–1250. https://doi.org/10.5194/gmd-7-1247-2014

Chen, Y., Zeng, X., Happiette, M., Bruniaux, P., Ng, R., & Yu, W. (2009). Optimisation of garment design using fuzzy logic and sensory evaluation techniques. *Engineering Applications of Artificial Intelligence*, *22*(2), 272–282. https://doi.org/10.1016/j.engappai.2008.05.007

Cox, J., & Dittmar, H. (1995). The functions of clothes and clothing (dis)satisfaction: A gender analysis among British students. *Journal of Consumer Policy*, *18*(2), 237–265. https://doi.org/10.1007/BF01016513

Cunningham, M. (2017). The value of color research in brand strategy. *Open Journal of Social Sciences*, *5*, 186–196. https://doi.org/10.4236/jss.2017.512014

Dong, M., Zeng, X., Koehl, L., & Zhang, J. (2020). An interactive knowledge-based recommender system for fashion product design in the big data environment. *Information Sciences*, *540*, 469–488. https://doi.org/10.1016/j.ins.2020.05.094

Elliot, A. J., & Maier, M. A. (2014). Color psychology: Effects of perceiving color on psychological functioning in humans. *Annual Review of Psychology*, *65*, 95–120. https://doi.org/10.1146/annurev-psych-010213-115035

Fan, J., Yu, W., & Hunter, L. (2004). *Clothing appearance and fit: Science and technology*. Elsevier Science.

Fehrman, C., & Fehrman, K. (2004). *Color: The secret influence*. Pearson Education.

Jackson, T., & Shaw, D. (2009). *Mastering fashion marketing* (Macmillan Master Series). Macmillan Education UK. https://doi.org/10.1007/978-1-137-09271-7

Li, S., Zhao, F., & Li, L. (2024). A review of noteworthy progress and opportunities in swimsuit design. *Textile Research Journal*, *94*(21–22), 2514–2527. https://doi.org/10.1177/00405175241245123

MacAdam, D. L. (1981). Color differences. In *Color measurement* (Vol. 27, pp. 104–133). Springer. https://doi.org/10.1007/978-3-662-13508-2_8

McLean, G., Osei-Frimpong, K., Al-Nabhani, K., & Marriott, H. (2020). Examining consumer attitudes towards retailers' m-commerce mobile applications – An initial adoption vs. continuous use perspective. *Journal of Business Research*, *106*, 139–157. https://doi.org/10.1016/j.jbusres.2019.08.032

Madden, T. J., Hewett, K., & Roth, M. S. (2000). Managing images in different cultures: A cross-national study of color meanings and preferences. *Journal of International Marketing*, *8*(4), 90–107. https://doi.org/10.1509/jimk.8.4.90.19795

Rocamora, A., & Smelik, A. (2015). *Thinking through fashion: A guide to key theorists* (Dress Cultures). Bloomsbury Publishing.

Tsawaab, A. H. (2023). The impact of body positivity in fashion advertising on customer perceptions and purchase intentions. *International Journal of Multidisciplinary: Applied Business and Education Research*, *4*(8), 2769–2784. https://doi.org/10.11594/ijmaber.04.08.10

Wang, L. C., Zeng, X. Y., Koehl, L., & Chen, Y. (2015). Intelligent fashion recommender system: Fuzzy logic in personalized garment design. *IEEE Transactions on Human-Machine Systems*, *45*(1), 95–109. https://doi.org/10.1109/THMS.2014.2364398

Wang, L., Zeng, X., Chen, Y., & Koehl, L. (2016). The use of fuzzy logic techniques to improve decision making in apparel supply chains. In T.-M. Choi (Ed.), *Information systems for the fashion and apparel industry* (pp. 9–39). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-100571-2.00002-6

Wei, S. (2024). Analysis of new media marketing strategies in the fast fashion industry. *Journal of Education, Humanities and Social Sciences*, *27*, 452–459. https://doi.org/10.54097/7va4kg02

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, *8*(3), 338–353. https://doi.org/10.1016/S0019-9958(65)90241-X