S & M 4305

IoT-enhanced Fuzzy-creative Quadrant Evaluation Framework for Cultural and Creative Products: A Case Study of Shanghai Jinshan Farmer Paintings

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(Received June 5, 2025; accepted January 15, 2026)

Keywords: IoT, enhanced fuzzy-creative quadrant evaluation framework, cultural and creative products, Shanghai Jinshan farmer paintings

In this study, we developed an IoT-enhanced fuzzy-creative quadrant evaluation framework that integrates fuzzy theory with the creative quadrant method to systematically assess the cultural and creative attributes of products. The framework was applied to the evaluation of cultural and creative product designs inspired by Shanghai Jinshan farmer paintings. By leveraging IoT technologies, a sensing-enabled data acquisition architecture was established, in which multiple sensors embedded in smart terminals, such as touch interaction sensors, display-based feedback sensors, and usage-behavior sensing modules, were employed to capture users' real-time interaction responses, preference signals, and contextual usage data. These sensor-generated data streams were aggregated through edge computing devices and analyzed to provide real-time insights into cultural trends and market dynamics. These data were transformed into interpretable market segmentation using fuzzy cultural market quadrant rules, enabling a more precise positioning of products within one of the four strategic quadrants. This data-driven approach assists designers and engineers in identifying product strengths and weaknesses with respect to innovation, aesthetic design, uniqueness, and cultural relevance. Evaluation results indicate that certain design proposals exhibit strong cultural and creative attributes, while others show the need for further enhancement in creativity or more comprehensive improvements across multiple dimensions. By explicitly integrating sensor-based perception, data sensing, and IoT-driven feedback mechanisms into the evaluation process, the proposed IoT-integrated fuzzy-creative quadrant framework offers an effective tool for guiding the development and market alignment of cultural and creative products, ultimately enhancing their commercial viability and competitive advantage from a sensing and smart-system perspective in the era of smart manufacturing and digital consumption.

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https://doi.org/10.18494/SAM5787

1. Introduction

Jinshan farmer paintings are a form of folk art from Shanghai's Jinshan district that emerged in the late 1950s. Created by local farmers to commemorate the founding of China, the works were first shown at the 1956 Shanghai Folk Art Exhibition. Early themes focused on socialist construction, production, and daily life, reflecting the era's strong social and regional identity. Over time, the subject matter broadened to include rural scenes, local customs, and folklore, while the art developed a distinctive style with bold colors and expressive forms. Now recognized as part of Shanghai's Intangible Cultural Heritage, these paintings have gained both local and national acclaim. As globalization and cultural diversity grow, the cultural and creative industries are becoming key drivers of economic development. The study of the commercialization of Jinshan farmer paintings thus has both theoretical and practical value. Lin *et al.* conducted a comprehensive analysis of integrating cultural elements into modern product design, emphasizing the balance between cultural preservation and market appeal.(1) Their research also pointed out the value of digital archives in safeguarding heritage and supporting cultural product design.(2)

The evaluation of cultural and creative products based on Shanghai Jinshan Farmer Paintings spans multiple fields, including tourism, economic development, and technology. Jinyi examined the integration of agriculture, tourism, and education through Jinshan farmer paintings to promote rural revitalization and cultural preservation.(3) Yang *et al.* explored the incorporation of folk art into product design to enhance cultural appeal and global recognition.(4) Jia *et al.* assessed the cultural landscape and economy of the Jinshan painting village, suggesting ways to attract more artists and tourists.(5) Wang and Aramusi applied style transfer algorithms to personalize and accelerate the design of watercolor-style cultural products, enhancing both aesthetics and market competitiveness.(6) Liu focused on the digitalization and commercialization of farmer paintings, advocating market expansion while preserving artistic integrity and addressing potential conflicts.(7) Studies on fuzzy logic in cultural product design have introduced various methods, emphasizing demand analysis, design element selection, multicriteria evaluation, customer preference integration, and automated tools. Su, using regional industrial competitiveness theory, applied the fuzzy Analytic Hierarchy Process (Fuzzy-AHP) to develop an evaluation index system for Henan's cultural industries.(8) This approach effectively quantified regional advantages, offering a data-driven foundation for policy decisions.

The use of fuzzy logic and related algorithms to evaluate cultural and creative products demonstrates how cultural elements can be integrated, thus enhancing the design process while ensuring market relevance. In their research, Hsueh and Huang employed the Delphi method to establish curriculum modules and applied fuzzy logic to develop an evaluation model.(9) Liu *et al.* combined the evaluation grid method (EGM) with fuzzy quality function deployment (QFD) to explore customer needs and design elements for cultural and creative products, providing clear, quantitative guidance throughout the design process.(10) Lan proposed an interactive color scheme design method based on triangular fuzzy numbers, incorporating user preferences and satisfaction into the design process of cultural and creative products.(11) This method emphasizes user participation and the integration of diverse preferences, using fuzzy logic to generate design solutions that meet the needs of the majority of customers, thereby enhancing both market competitiveness and user satisfaction.

As global interest in personalized and culturally rich products grows, the development and evaluation of such products remain largely subjective, often dependent on designer intuition. To address this, researchers have integrated quantitative tools into creative evaluation models. One such approach—the fuzzy-creative quadrant method—combines fuzzy logic with the creative quadrant model to assess innovation, aesthetic value, and uniqueness. However, traditional applications lack real-time consumer data and adaptability to changing market demands.

To address the lack of real-time consumer insight in existing evaluation models, in this study, we developed an IoT-enhanced evaluation framework that integrates the fuzzy-creative quadrant method with large-scale, real-time data acquisition. IoT technologies, including embedded sensors, mobile apps, and cloud analytics, enable the continuous collection of user data such as browsing time, purchase frequency, design preferences (e.g., color and motif), and location-based cultural trends. By incorporating these data streams into a fuzzy inference system, designers gain a more precise, data-driven view of how cultural products are perceived in the market. The system framework consists of three modules: (1) an IoT-based data acquisition layer that gathers consumer interaction data via smart devices and digital platforms; (2) a fuzzy inference and quadrant mapping module that classifies products into cultural-creative quadrants based on design and consumer input; and (3) a visualization and feedback module that presents results and provides actionable recommendations for product development. This creates a closed-loop system where design decisions are continuously refined using real-world feedback.

A case study on cultural products derived from Shanghai Jinshan farmer paintings validates the framework. By analyzing three design proposals, the system identifies the strengths, areas for improvement (e.g., innovation or uniqueness), and options most aligned with market needs. The fuzzy-creative quadrant method, combining fuzzy theory and the creative quadrant model, categorizes products into four types—cultural goods, creative goods, general goods, and cultural-creative goods—based on attributes.[12] Cultural attributes include traditional themes, color schemes, and painting techniques, while creative attributes focus on innovation, functionality, and aesthetic value. Applying this method to Jinshan farmer paintings helps assess both market competitiveness and cultural value, offering targeted recommendations for improvement. While prior studies have explored aspects of Jinshan farmer paintings, clear evaluation criteria remain underdeveloped. This research fills that gap by proposing a systematic, data-driven framework for assessing cultural, economic, and artistic value, serving not only Jinshan-related products but also as a model for evaluating other cultural and creative works.

2. Methodology

Fuzzy-AHP is a method that combines the traditional AHP with fuzzy logic to handle the uncertainty and imprecision often encountered in decision-making processes. This method is particularly useful in situations where decision criteria are subjective or ambiguous. By incorporating fuzzy logic, Fuzzy-AHP allows for a more flexible and realistic modeling of preferences, leading to more robust decision outcomes. In this study, the Fuzzy-AHP method is further extended by integrating the fuzzy cultural market quadrant method with IoT technology, thereby forming a sensor-driven evaluation framework. This integration enables not only structured multicriteria decision analysis but also continuous data acquisition through sensing mechanisms. Unlike conventional questionnaire-based evaluations, the proposed framework emphasizes the use of sensors as primary data sources, allowing implicit user perceptions and behavioral responses to be objectively captured and quantified. The combination offers a more precise and dynamic approach to cultural market analysis, supporting the real-time monitoring of user engagement and preference evolution. The relationship between the fuzzy cultural market quadrant method and IoT technology can be understood from several aspects: data-driven insights, fuzzy processing, personalized recommendations, and dynamic analysis. In particular, the sensing concept serves as the foundation that links the physical interaction layer with the fuzzy decision-making layer, enabling raw sensor signals to be transformed into meaningful evaluation indicators. The detailed steps and methods are described below.

2.1 IoT-based data acquisition layer

The first step of the proposed methodology is the design and implementation of an IoT-based infrastructure that enables real-time data collection through distributed sensing units. This infrastructure utilizes specific IoT technologies, including radio frequency identification (RFID) for tracking product handling, Bluetooth low energy (BLE) beacons for proximity sensing, mobile device sensors (e.g., accelerometers and GPS) for movement and location tracking, and quick-response code scanners for linking physical products with digital content. These sensing components collectively form a multimodal sensor network, capable of capturing users' spatial behavior, interaction intensity, and contextual engagement with cultural and creative products. Smart displays embedded with touchscreen interfaces act as human–machine interaction sensors, recording touch frequency, dwell duration, navigation paths, and selection behavior. Edge computing devices (e.g., Raspberry Pi or Arduino-based controllers) are installed in physical retail environments and exhibitions to preprocess sensor data locally, reducing latency and bandwidth consumption while preserving data fidelity. This edge-level sensing and preprocessing mechanism ensures timely response and improves the robustness of the overall system.

User interfaces are developed in the form of IoT-connected mobile applications and interactive web platforms, enabling users to browse cultural and creative products, submit ratings, customize design features, and interact with Augmented Reality/Virtual Reality-enhanced content. From a sensing perspective, these interfaces function as soft sensors, translating subjective user perceptions, such as aesthetic preference, cultural resonance, and emotional response, into quantifiable digital signals. To ensure efficient data transmission, the infrastructure employs lightweight IoT communication protocols, including Message Queuing Telemetry Transport (MQTT) for low-latency sensor communication and HyperText Transfer Protocol (HTTP/HTTPS) for secure data exchange. Sensor data streams are transmitted to cloud platforms such as Amazon Web Services IoT Core or Google Cloud IoT, which handle device management, message routing, real-time analytics, and long-term storage. These platforms further support data visualization dashboards and AI-driven analytics services.

The system captures a broad spectrum of sensor-derived data, including dwell time near specific exhibits or products (via BLE/RFID), interaction frequency and duration (via touchscreen and application sensors), customization preferences (e.g., selected motifs or colors), purchase intent signals inferred from interaction patterns, demographic attributes obtained from user profiles, geolocation metadata (from mobile GPS), and real-time feedback in the form of product ratings and textual comments. Through sensor fusion and data aggregation, heterogeneous sensing signals are integrated into unified evaluation features, which subsequently serve as inputs to the Fuzzy-AHP and fuzzy cultural market quadrant analysis. Overall, this IoT-enabled, sensor-centric data acquisition layer establishes a dynamic and comprehensive digital representation of user engagement with cultural and creative products. By embedding sensing mechanisms throughout the evaluation pipeline, the proposed methodology ensures objectivity, continuity, and scalability in data collection, thereby strengthening the reliability of downstream fuzzy decision-making and market positioning.

Importantly, the collected sensor-derived data are not treated as standalone descriptive statistics or subjective survey responses. Instead, they are systematically mapped to the evaluation criteria used in the Fuzzy-AHP and fuzzy cultural market quadrant framework. Specifically, sensor-measured dwell time and interaction frequency are used as quantitative indicators of user engagement and perceived attractiveness; touchscreen navigation depth and selection patterns reflect design intuitiveness and aesthetic appeal; customization choices captured through interfaces indicate creativity preference and uniqueness; while repeat interactions and prolonged proximity signals are interpreted as proxies for cultural resonance and emotional attachment. These sensor-based indicators are normalized and aggregated through sensor fusion and preprocessing procedures, forming objective feature vectors that serve as inputs for the fuzzy evaluation process. Expert judgments are then employed primarily to calibrate the relative importance (weights) of evaluation criteria, rather than to replace sensor observations. In this way, the proposed framework establishes a clear sensing-to-evaluation pipeline, where sensors provide continuous, behavior-based evidence and Fuzzy-AHP operates on sensor-informed indicators, effectively distinguishing the methodology from conventional opinion surveys.

2.2 Identify goals and attributes and data collection

Our goal is to enhance the overall quality and customer satisfaction of cultural and creative products or services. This includes improving the appeal and visitor experience of cultural products, cultural events, and museum exhibitions. Key attributes important to cultural and creative products or services should be identified and categorized into cultural and creative attributes. To begin, a questionnaire can be designed to gather evaluations from customers or visitors regarding various attributes, including both cultural and creative aspects. It may be helpful to use fuzzy semantic variables for data collection, such as a 5-point fuzzy rating scale. Following this, IoT technology can be employed to collect and transmit the data. Ultimately, evaluation data from experts, customers, or visitors can be compiled, and the fuzzy semantic variables can be converted into fuzzy numbers for further analysis.

2.3 Data analyses

Initially, fuzzy number processing may involve converting fuzzy evaluations into triangular or trapezoidal fuzzy numbers. Triangular fuzzy numbers, which are commonly used for this purpose (as shown in Table 1), are defined as $\tilde{\boldsymbol{A}} = (\boldsymbol{a}_1, \boldsymbol{a}_2, \boldsymbol{a}_3)$, where a_1 represents the lower bound, a_2 is the most likely value (the central value), and a_3 represents the upper bound of the fuzzy number.

Then, we perform operations with fuzzy numbers: given two triangular fuzzy numbers, $\tilde{\boldsymbol{A}}_1 = (\boldsymbol{a}_{11}, \boldsymbol{a}_{12}, \boldsymbol{a}_{13})$ and $\tilde{\boldsymbol{A}}_2 = (\boldsymbol{a}_{21}, \boldsymbol{a}_{22}, \boldsymbol{a}_{23})$, their sum is

$$\tilde{\boldsymbol{A}}_1 + \tilde{\boldsymbol{A}}_2 = (\boldsymbol{a}_{11} + \boldsymbol{a}_{21}, \boldsymbol{a}_{12} + \boldsymbol{a}_{22}, \boldsymbol{a}_{13} + \boldsymbol{a}_{23}). \tag{1}$$

For n number of triangular fuzzy numbers $\tilde{\boldsymbol{A}}_1, \tilde{\boldsymbol{A}}_2, \cdots, \tilde{\boldsymbol{A}}_n$, their average fuzzy number is

$$\tilde{A} = \left(\frac{1}{n} \sum_{i=1}^{n} a_{i1}, \frac{1}{n} \sum_{i=1}^{n} a_{i2}, \frac{1}{n} \sum_{i=1}^{n} a_{i3} \right). \tag{2}$$

In the fuzzy-cultural creative quadrant method, to more accurately reflect the impact of each attribute, we use a given set of n triangular fuzzy numbers $\tilde{\boldsymbol{A}}_1, \tilde{\boldsymbol{A}}_2, \cdots, \tilde{\boldsymbol{A}}_n$ along with their corresponding weights $\boldsymbol{w}_1, \boldsymbol{w}_2, \ldots, \boldsymbol{w}_n$. The weighted fuzzy average is then calculated as

$$\tilde{A} = \left(\frac{1}{n} \sum_{i=1}^{n} w_i a_{i1}, \frac{1}{n} \sum_{i=1}^{n} w_i a_{i2}, \frac{1}{n} \sum_{i=1}^{n} w_i a_{i3} \right), \tag{3}$$

where w_i represents the weight of the i-th attribute and satisfies the condition $\sum_{i=1}^{n} w_i = 1$. To ensure data consistency, the data should be normalized. The standardized score can be obtained as

$$z = \frac{x - \mu}{\sigma}, \tag{4}$$

where x is the original score to be normalized, μ is the population mean, and $\sigma \neq 0$ is the population standard deviation. The z-value represents the distance between the original score

Table 1
Triangular fuzzy numbers.

Semantic wording	Triangular fuzzy numbers
Extremely important	(0.8, 1, 1)
Important	(0.6, 0.8, 1)
Moderate	(0.4, 0.6, 0.8)
Unimportant	(0.2, 0.4, 0.6)
Extremely unimportant	(0, 0, 0.2)

and the population mean, measured in units of standard deviation. When the original score is below the mean, the z-value will be negative; when it is above the mean, the z-value will be positive. In other words, the z-value indicates how many standard deviations the point of interest is from the mean. Next, we calculate the consistency index (CI) and the consistency ratio (CR). CI is computed based on the fuzzy evaluation matrix as

$$CI = \frac{\lambda_{max} - n}{n-1} \text{ and } CR = \frac{CI}{RI}, \quad (5)$$

where λ_{max} is the largest eigenvalue of the matrix, n is the size of the matrix, and RI is the random consistency index, which can be obtained from a table based on the matrix size.

2.4 Create a fuzzy-cultural creative quadrant diagram

In the diagram, the horizontal axis represents the standardized values of the fuzzy cultural attribute ($\tilde{\boldsymbol{A}}_j$), while the vertical axis represents the standardized values of the fuzzy creative attribute ($\tilde{\boldsymbol{C}}_j$). On the basis of the standardized values of the fuzzy cultural and creative attributes, the coordinate system is divided into four quadrants, as shown in Fig. 1.

(a) The cultural and creative commodity quadrant represents high cultural and creative attributes, indicating strong performance.
(b) The cultural commodity quadrant represents high cultural attributes but low creative attributes, suggesting a need for improvement in creativity.
(c) The creative commodity quadrant represents low cultural attributes but high creative attributes, indicating a need for enhancement in cultural aspects.
(d) The general commodity quadrant represents both low cultural and creative attributes, requiring overall improvement.

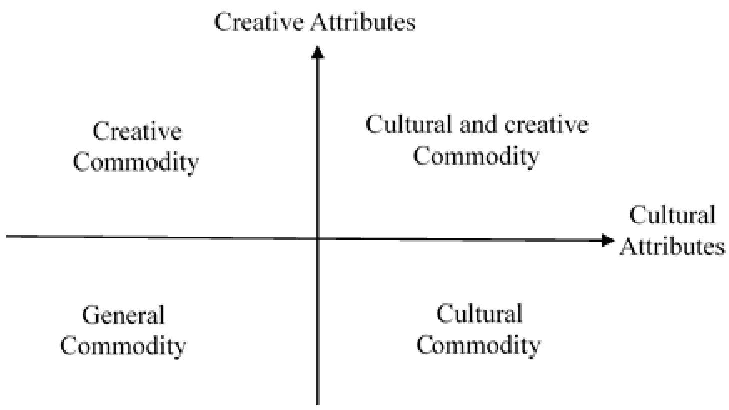

Fig. 1. Fuzzy quadrants of cultural creativity.

3. Application of Fuzzy-cultural Creative Quadrant Method to the Evaluation of Cultural and Creative Products in the Shanghai Jinshan Farmer Painting Sector

The fuzzy-cultural creative quadrant method integrates fuzzy theory with cultural and creative attributes, effectively addressing their inherent vagueness. This approach supports the more accurate identification and optimization of key product features. Figure 2 shows the evaluation process for three design options based on Shanghai Jinshan farmer paintings.

Option A: Spring in the East. White magnolias bloom among traditional pavilions in the foreground, while the Oriental Pearl Tower rises in the background. The layered composition blends Jiangnan architectural charm with urban grandeur, reflecting a balance between classical beauty and modern progress.

Option B: Golden Rooster and Big and Small Jinshan. With vivid colors, dynamic layout, and distinctive patterns, this piece captures the morning glow over Jinshan. The thoughtful use of white space highlights the exaggerated style of farmer paintings, set against a crisp white sky filled with mist and clouds.

Option C: Fish and Lotus in Summer. Inspired by fish swimming in a lotus pond, the design symbolizes harmony, prosperity, and openness. Lotus pods suggest abundance, while upright stems imply connection. The overall mood is gentle and poetic, conveying peaceful and auspicious imagery.

3.1 Defining objectives and attributes

In this study, we aimed to evaluate the cultural and creative attributes of Shanghai Jinshan farmer-painting-derived products, identifying their strengths and areas for improvement. Given the limited prior research on relevant evaluation criteria, in this study, we first reviewed literature from domestic and international journals, papers, and reports. From the collected data, key factors affecting the cultural and creative value of products were extracted and structured into a preliminary evaluation framework. Through group discussions, these factors were refined

Option A	Option B	Option C
Intangible cultural heritage infuser teacup set	Shanghai specialty intangible cultural heritage tea set	Intangible cultural heritage infuser teacup set in ceramic

Fig. 2. (Color online) Three cultural and creative product plans based on Shanghai Jinshan farmer paintings.

and categorized into two main dimensions, cultural and creative attributes, each with specific indicators, as detailed in Table 2.

3.2 Data collections

In this study, we recruited 15 experts in art design, cultural studies, creative industries, and craft arts, all with master's or doctoral degrees and over 10 years of professional experience. A structured questionnaire was used to evaluate key cultural attributes (traditional style, design sense, color use, painting technique, and storytelling) and creative attributes (innovation, aesthetics, functionality, uniqueness, and overall value). Responses were collected using a 5-point fuzzy evaluation scale with fuzzy semantic variables. The expert evaluation results are statistically analyzed, and the corresponding triangular fuzzy numbers are presented in Table 3.

3.3 Data analyses

To facilitate understanding for readers who may not be familiar with fuzzy logic and related decision-making algorithms, Fig. 3 shows a schematic of the overall flow of the data analysis process adopted in this study. The diagram shows the sequential steps from expert evaluation data collection to fuzzy aggregation, defuzzification, and final weight normalization. Specifically, expert judgments are first collected through pairwise comparisons and transformed into fuzzy numbers. These fuzzy evaluations are then aggregated across all experts to obtain representative fuzzy values for each indicator. Subsequently, defuzzification is performed to convert fuzzy values into crisp weights, followed by normalization to derive the final relative importance of each indicator used in the fuzzy-cultural creative quadrant analysis.

Table 2
Evaluation criteria for Shanghai Jinshan farmer-painting-derived cultural and creative products.

Attributes	Indicators	Content
Cultural attributes	Traditional style	Whether the product retains and reflects the artistic style and elements of traditional culture
	Design sense	Whether the product reflects themes from traditional paintings, such as folklore, historical events, etc.
	Color usage	Whether the product uses color combinations and color symbolism from traditional culture
	Painting technique	Whether the product employs traditional painting technique and craft methods
	Narrative quality	Whether the product's design tells a story and evokes an emotional connection with the audience
Creative attributes	Innovation	Novelty and creativity of the product's design and concept
	Design aesthetic	Whether the product's design possesses visual appeal and attractiveness
	Practicality	Whether the product has practical use value and meets the consumer's everyday needs
	Uniqueness	Whether the product features a unique design and style that allows it to stand out in the market
	Aesthetic value	Whether the product has artistic value and can be appreciated and collected as an artwork

Table 3
Triangular fuzzy numbers for experts' evaluations of cultural and creative attributes.

Expert	1	2	3	4	5	6	7	8
Traditional style	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)
Design sense	(0.6, 0.8, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.8, 1, 1)
Color usage	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.4, 0.6, 0.8)	(0.6, 0.8, 1)
Painting technique	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.4, 0.6, 0.8)	(0.6, 0.8, 1)
Narrative quality	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.4, 0.6, 0.8)	(0.6, 0.8, 1)
Innovation	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)
Design aesthetic	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)
Practicality	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.4, 0.6, 0.8)	(0.6, 0.8, 1)
Uniqueness	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)
Aesthetic value	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)

Expert	9	10	11	12	13	14	15
Traditional style	(0.6, 0.8, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)
Design sense	(0.8, 1, 1)	(0.6, 0.8, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)
Color usage	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)
Painting technique	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)
Narrative quality	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)
Innovation	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)
Design aesthetic	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)
Practicality	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)	(0.6, 0.8, 1)
Uniqueness	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)
Aesthetic value	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)	(0.8, 1, 1)

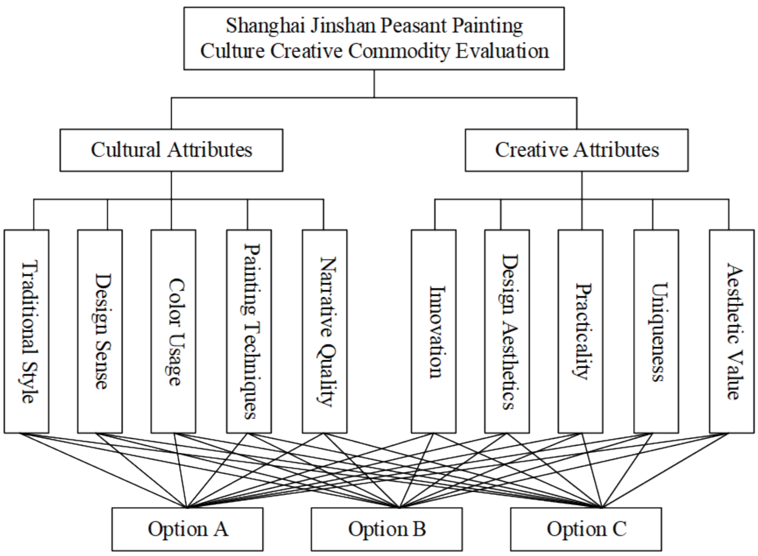

Fig. 3. Schematic of overall flow of data analysis process.

For each indicator, it is necessary to calculate the fuzzy average of the evaluation results from all experts using the analyzed data. Table 4 presents the fuzzy averages for each indicator based on the experts' evaluations. Table 5 shows the defuzzified and normalized weights for each indicator.

Table 6 shows the normalized weights of each indicator classified into the following four groups.

(a) The top indicators—innovation, design sensibility, uniqueness, and aesthetic value—-hold the highest weights, reflecting experts' views that these attributes are most critical for product success and market competitiveness.

(b) A moderate indicator—traditional style—has a slightly lower but still significant weight, indicating experts value maintaining tradition alongside innovation and design.

Table 4
Fuzzy averages of expert evaluation results.

Indexes	Fuzzy averages	Indexes	Fuzzy averages
Traditional style	(0.8, 1, 1)	Innovation	(0.8, 1, 1)
Design sense	(0.8, 1, 1)	Design aesthetic	(0.8, 1, 1)
Color usage	(0.6, 0.8, 1)	Practicality	(0.6, 0.8, 1)
Painting technique	(0.6, 0.8, 1)	Uniqueness	(0.8, 1, 1)
Narrative quality	(0.6, 0.8, 1)	Aesthetic value	(0.8, 1, 1)

Table 5
Defuzzified and normalized weights for each indicator.

Indexes	Fuzzy weights	Defuzzified weights	Normalized weights
Traditional style	(0.770, 0.971, 1.000)	0.914	0.106
Design sense	(0.686, 0.888, 1.000)	0.858	0.099
Color usage	(0.584, 0.785, 0.985)	0.785	0.091
Painting technique	(0.584, 0.785, 0.985)	0.785	0.091
Narrative quality	(0.584, 0.785, 0.985)	0.785	0.091
Innovation	(0.800, 1.000, 1.000)	0.933	0.108
Design aesthetic	(0.800, 1.000, 1.000)	0.933	0.108
Practicality	(0.584, 0.785, 0.985)	0.785	0.091
Uniqueness	(0.800, 1.000, 1.000)	0.933	0.108
Aesthetic value	(0.800, 1.000, 1.000)	0.933	0.108

Table 6
Fuzzy averages of cultural and creative attribute evaluations.

Indexes	Lower bound (a)	Middle value (b)	Upper bound (c)
Traditional style	0.8	1	1
Design sense	0.8	1	1
Color usage	0.6	0.8	1
Painting technique	0.6	0.8	1
Narrative quality	0.6	0.8	1
Innovation	0.8	1	1
Design aesthetic	0.8	1	1
Practicality	0.6	0.8	1
Uniqueness	0.8	1	1
Aesthetic value	0.8	1	1

(c) A lower indicator—artwork theme—carries moderate effect and is recognized by experts but is less critical than top attributes.

(d) The lowest indicators—color usage, painting technique, storytelling, and practicality—have the least weight, meaning they are less important in this product and market context, though not unimportant.

Next, the expert survey results were converted into fuzzy data to construct the fuzzy evaluation matrix using the previously calculated fuzzy averages. These averages, expressed as triangular fuzzy numbers (a, b, c) representing lower, middle, and upper bounds, capture the evaluation of cultural and creative attributes. Figure 4 presents the fuzzy evaluation matrix constructed for the Fuzzy-AHP analysis. Each row of the matrix corresponds to an evaluation criterion (e.g., innovation, design sense, uniqueness, aesthetic value, and cultural relevance), while each column represents the relative importance of these criteria derived from expert pairwise comparisons. The matrix elements are expressed as fuzzy numbers, reflecting the uncertainty and subjectivity inherent in expert judgments. This matrix serves as the fundamental input for subsequent weight calculation and consistency verification in the Fuzzy-AHP procedure. Consistency indices are then calculated, yielding a CI of 3.95×10^{-16} and a CR of 2.65×10^{-16}. Since the CR is much smaller than 0.1, the experts' evaluations demonstrate a very high consistency.

Similarly, using the evaluation results of experts for the product options A, B, and C across various indicators, the evaluation data are converted into triangular fuzzy numbers, as shown in Table 7. Next, fuzzy averages are calculated. Following this, the defuzzified weights for each indicator are computed, as shown in Table 8. Finally, the normalized weights are multiplied by the defuzzified weights for each option to obtain the weighted defuzzified values for the indicators of the three options, as shown in Table 9.

In option A, the highest weighted defuzzified values are for innovation, design sense, uniqueness, and aesthetic value (all 0.933). This indicates that these factors are considered the most important according to expert evaluations. On the other hand, the factors with lower weighted defuzzified values are color usage, painting technique, narrative quality, and practicality (all 0.785), suggesting that these aspects are deemed less significant in the expert assessments. In option B, the highest weighted defuzzified values are for innovation, design sense, uniqueness, and aesthetic value (all 0.900). This indicates that these factors are considered the most important in expert evaluations. Conversely, the factors with lower weighted defuzzified values are color usage, painting technique, narrative quality, and practicality (all

$$\begin{bmatrix}
1.00 & 1.00 & 1.25 & 1.25 & 1.25 & 1.00 & 1.00 & 1.25 & 1.00 & 1.00 \\
1.00 & 1.00 & 1.25 & 1.25 & 1.25 & 1.00 & 1.00 & 1.25 & 1.00 & 1.00 \\
0.80 & 0.80 & 1.00 & 1.00 & 1.00 & 0.80 & 0.80 & 1.00 & 0.80 & 0.80 \\
0.80 & 0.80 & 1.00 & 1.00 & 1.00 & 0.80 & 0.80 & 1.00 & 0.80 & 0.80 \\
0.80 & 0.80 & 1.00 & 1.00 & 1.00 & 0.80 & 0.80 & 1.00 & 1.00 & 1.00 \\
1.00 & 1.00 & 1.25 & 1.25 & 1.25 & 1.00 & 1.00 & 1.25 & 1.00 & 1.00 \\
1.00 & 1.00 & 1.25 & 1.25 & 1.25 & 1.00 & 1.00 & 1.25 & 1.00 & 1.00 \\
0.80 & 0.80 & 1.00 & 1.00 & 1.00 & 0.80 & 0.80 & 1.00 & 0.80 & 0.80 \\
1.00 & 1.00 & 1.25 & 1.25 & 1.25 & 1.00 & 1.00 & 1.25 & 1.00 & 1.00 \\
1.00 & 1.00 & 1.25 & 1.25 & 1.25 & 1.00 & 1.00 & 1.25 & 1.00 & 1.00
\end{bmatrix}$$

Fig. 4. Fuzzy evaluation matrix.

Table 7
Triangular fuzzy numbers for indicators of the three options.

Indexes	Fuzzy weights		
	Option A	Option B	Option C
Traditional style	(0.713,0.915,1.000)	(0.648,0.849,1.000)	(0.446,0.648,0.849)
Design sense	(0.673,0.875,1.000)	(0.510,0.713,0.915)	(0.276,0.483,0.686)
Color usage	(0.584,0.785,0.985)	(0.483,0.686,0.888)	(0.382,0.584,0.785)
Painting technique	(0.584,0.785,0.985)	(0.600,0.800,1.000)	(0.382,0.584,0.785)
Narrative quality	(0.584,0.785,0.985)	(0.483,0.686,0.888)	(0.276,0.483,0.686)
Innovation	(0.800,1.000,1.000)	(0.686,0.888,1.000)	(0.276,0.483,0.686)
Design aesthetic	(0.800,1.000,1.000)	(0.686,0.888,1.000)	(0.276,0.483,0.686)
Practicality	(0.584,0.785,0.985)	(0.483,0.686,0.888)	(0.276,0.483,0.686)
Uniqueness	(0.800,1.000,1.000)	(0.686,0.888,1.000)	(0.276,0.483,0.686)
Aesthetic value	(0.800,1.000,1.000)	(0.800,1.000,1.000)	(0.276,0.483,0.686)

Table 8
Defuzzified weights for indicators of the three options.

Indexes	Defuzzified values		
	Option A	Option B	Option C
Traditional style	0.876	0.832	0.648
Design sense	0.849	0.713	0.482
Color usage	0.785	0.686	0.584
Painting technique	0.785	0.800	0.584
Narrative quality	0.785	0.686	0.482
Innovation	0.933	0.858	0.686
Design aesthetic	0.933	0.858	0.686
Practicality	0.785	0.686	0.482
Uniqueness	0.933	0.858	0.686
Aesthetic value	0.933	0.933	0.686

Table 9
Weighted defuzzified values for indicators of the three options.

Indexes	Normalized weights	Weighted defuzzified values		
		Option A	Option B	Option C
Traditional style	0.106	0.093	0.088	0.069
Design sense	0.099	0.084	0.071	0.048
Color usage	0.091	0.071	0.062	0.053
Painting technique	0.091	0.071	0.073	0.053
Narrative quality	0.091	0.071	0.062	0.044
Innovation	0.108	0.101	0.093	0.074
Design aesthetic	0.108	0.101	0.093	0.074
Practicality	0.091	0.071	0.062	0.044
Uniqueness	0.108	0.101	0.093	0.074
Aesthetic value	0.108	0.101	0.093	0.074

0.778), suggesting that these aspects are deemed less significant in the expert assessments. In option C, the highest weighted defuzzified values are for innovation, design sense, uniqueness, and aesthetic value (all 0.850). This indicates that these factors are considered the most important according to expert evaluations. Conversely, the factors with lower weighted defuzzified values are color usage, painting technique, narrative quality, and practicality (all 0.714), suggesting that these aspects are regarded as less significant in the expert assessments. The Z-scores for cultural and creative attributes across different schemes were calculated, as shown in Table 10. This allows for a comparative analysis of the relative positions of cultural and creative attributes within each scheme. By examining these Z-scores, we can better understand how each scheme performs in terms of cultural and creative aspects relative to the others.

3.4 Constructing the 2D fuzzy cultural and creative quadrant diagram

The horizontal axis represents the standardized values of the fuzzy cultural attributes ($\tilde{A}_j$), while the vertical axis represents the standardized values of the fuzzy creative attributes ($\tilde{C}_j$). Each option—A, B, or C—is plotted on the coordinate system in accordance with its fuzzy standard scores for cultural and creative attributes. As shown in Fig. 5, Scheme A is placed in the cultural and creative product quadrant, performing well in both cultural and creative attributes. This indicates that Option A has strong cultural and creative value and is suitable for products emphasizing innovation and heritage. Option B also falls within the same quadrant but scores higher in cultural attributes and lower in creative ones, suggesting that it has cultural value but needs improvements in creativity and design. Option C is positioned in the general product quadrant, showing weaker performance in both areas, indicating that it lacks significant cultural and creative value and requires considerable enhancements to boost market competitiveness. Overall, Fig. 4 demonstrates that this methodology effectively guides improvement strategies by

Table 10
Standardized values for the three different options.

Option	Weighted defuzzified values		Z-score	
	Cultural attribute	Creative attribute	Cultural attribute	Creative attribute
A	0.078	0.095	0.827	0.841
B	0.071	0.087	0.284	0.264
C	0.053	0.068	−1.111	−1.106

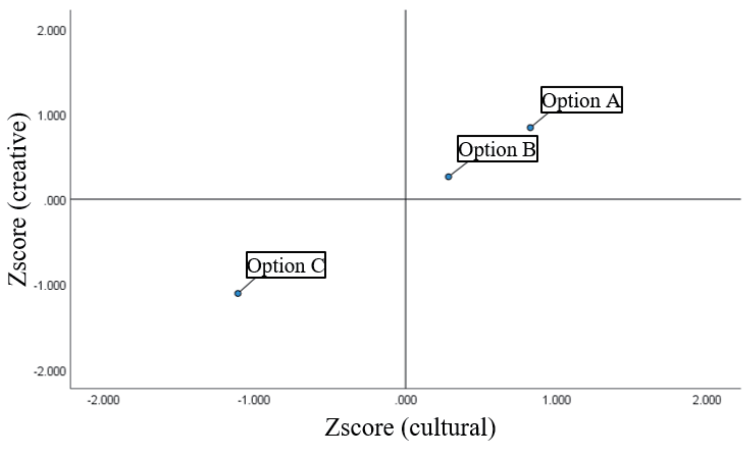

Fig. 5. Fuzzy cultural and creative quadrant diagram.

pinpointing key strengths and weaknesses for each option and recommending targeted actions accordingly.

4. Conclusions

The fuzzy-cultural creative quadrant method uses fuzzy logic to help decision-makers evaluate cultural and creative products under uncertainty. Applied to Shanghai Jinshan farmer paintings, this method supports analysis and product selection. Key findings include the following:

(a) Innovation, design sense, uniqueness, and aesthetic value are the most important attributes and are crucial for enhancing competitiveness and appeal.
(b) Traditional style and painting themes also hold significant cultural value.
(c) Color usage, painting technique, narrative quality, and practicality, reflecting product quality and user experience, are important but secondary.

By integrating IoT technology, sensor-enabled data acquisition mechanisms are incorporated into the evaluation framework, allowing real-time consumer data, such as interaction behavior, preference signals, and contextual usage patterns, to be continuously collected. These data are captured through multiple sensing channels, including touchscreen interaction sensors, proximity and location sensors, and mobile device sensors, and subsequently transformed into quantitative indicators suitable for fuzzy evaluation. As a result, the proposed approach moves beyond static, questionnaire-based assessments toward a dynamic sensing-driven evaluation paradigm. This integration enables more accurate and adaptive evaluations, as changes in consumer behavior and preferences can be promptly reflected in the fuzzy-cultural creative quadrant analysis. This sensing concept serves as a critical bridge between physical user interaction and abstract decision modeling, enhancing the objectivity and responsiveness of product assessment. Overall, the fuzzy-cultural creative quadrant method, enhanced by IoT-based sensing and real-time data feedback, provides a comprehensive understanding of the key factors affecting the design and market positioning of Jinshan farmer paintings products. The proposed framework effectively guides differentiated design and development strategies, contributing to the creation of more innovative, culturally resonant, and market-aligned cultural and creative products within a smart sensing and digital consumption environment.

Acknowledgments

This work is supported by Summit-Tech Resource Corp. and by projects under Nos. NSTC 113-2622-E-390-001 and NSTC 113-2221-E-390-011.

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