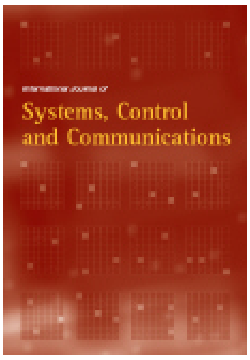

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An intelligent fuzzy evaluation model for digital heritage design: a cyber-physical systems perspective on closed-loop feedback mechanisms

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An intelligent fuzzy evaluation model for digital heritage design: a cyber-physical systems perspective on closed-loop feedback mechanisms

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Abstract: This paper proposes an intelligent fuzzy evaluation model that integrates grounded theory (GT), analytic hierarchy process (AHP), and fuzzy comprehensive evaluation (FCE). This model is designed as an 'evaluation controller' in the AIGC generation network, specifically for quantifying the cultural heritage value of Yixing Zisha teapot designs and providing closed-loop feedback. This study extracted the hierarchical state feature space consisting of four dimensions: instinctive layer, behavioural layer, reflective layer, and evolutionary layer through semi-structured interviews and three-level coding. Simulation experiments and multi-source data fusion analysis shows the model can objectively select the optimal design with strong anti-disturbance ability and in line with contemporary aesthetic standards and output precise quantitative error signals to guide the state correction and parameter iteration of the generation system. This research provides a scientific and computable intelligent decision-making and control paradigm for the digital protection and sustainable innovation of intangible cultural heritage under multi-agent systems.

Keywords: cyber-physical systems; CPS; fuzzy comprehensive evaluation; FCE; networked control; artificial intelligence generated content; AIGC; Yixing Zisha pottery; intangible cultural heritage; ICH; multi-criteria decision making.

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1 Introduction

In the context of the globalised information era and the deepening of the digital wave, computing, communication, and control network capabilities (cyber-capabilities) have been deeply integrated into various physical entities ranging from micro-level hardware components to macro-level system engineering. This information physical system [cyber-physical systems (CPS)] paradigm not only reshapes modern industrial manufacturing and sensor networks, but also provides an unprecedented control theoretical perspective for the digital twins, feature acquisition, and knowledge inheritance of traditional intangible cultural heritage (ICH) (Zadeh, 1965; Saaty, 2002). The Yixing Zisha teapot-making technique, as the pinnacle representative of traditional Chinese craftsmanship, enjoys worldwide acclaim due to its unique dual air-hole material physical characteristics (breathable but impermeable to water) and its high integration with classical philosophy. It was listed as a national ICH in the early days (Throsby, 1999). However, with the changes in modern consumption patterns, the traditional design of Yixing Zisha teapots heavily relies on the tacit knowledge of artisans and the oral transmission from master to apprentice, and is facing systematic bottlenecks such as severe design homogeneity and difficulty in responding to the demands of large-scale customisation networks (Norman, 2007; Baheti and Gill, 2011).

In recent years, artificial intelligence-generated content (AIGC) technology has demonstrated revolutionary potential in computer vision and multi-agent networks. By leveraging deep learning and massive data processing capabilities, AIGC can act as an executor to quickly generate highly visually diverse three-dimensional design proposals (He et al., 2023; Zhao et al., 2024). However, when this underlying probabilistic distribution-based generation technology is directly applied to the design of traditional Yixing Zisha teapots, significant 'control failure' and 'semantic disturbance' occur. Machine-generated designs of Zisha teapots often feature attractive geometric forms but lack an understanding of fluid dynamics, centre-of-gravity distribution, and other physical behaviours, making it even more difficult to convey deep cultural connotations such as 'roundness within the square' (Nisiotis et al., 2025; Wang, 2025). In the context of system control theory, this phenomenon can be regarded as an open-loop system with severe disturbances. Due to the lack of effective state observation and feedback calibration mechanisms for cultural heritage value, AI-generated designs often diverge and deviate from the set point of traditional craftsmanship, posing a risk of alienating cultural genes (Hu et al., 2025; Pan et al., 2025).

To bridge the gap between digital innovation and heritage protection, it is particularly crucial to establish a scientific, objective, and closed-loop evaluation mechanism capable of handling subjective ambiguity. In complex control engineering and multi-criteria decision-making (MCDM), fuzzy logic is widely applied to handle system evaluation problems involving uncertainties and nonlinear human cognition (He et al., 2024; Xu, 2024). Based on this, this study aims to construct an intelligent fuzzy evaluation model that integrates the concept of information feedback control, with the intention of quantitatively observing and dynamically evaluating the cultural heritage value of AIGC Zisha teapot designs (Zhao et al., 2025; Gu and Hein, 2023).

The core contributions of this study are as follows:

1. Constructing the cultural state observation space: Breaking through the previous limitation where the evaluation of saucer-shaped pottery designs overly relied on subjective qualitative descriptions, a hierarchical evaluation index system consisting of four dimensions – instinct, behaviour, reflection, and evolution – was constructed based on grounded theory (GT).
2. Proposing a quantitative evaluation algorithm framework: Integrating the analytic hierarchy process (AHP) and the fuzzy comprehensive evaluation (FCE) method, a

mathematical calculation model was established that can map complex cultural attributes and aesthetic perceptions into precise control signals.

3 Designing a closed-loop feedback control system: Placing this evaluation model within the metaphorical framework of CPSs, it acts as an 'evaluation controller' in the networked control system (NCS) architecture. It provides explicit quantitative error feedback for disturbance rejection, enabling dynamic closed-loop optimisation for generative AI and directly contributing to multi-agent cultural computing.

2 Related work and theoretical foundation

2.1 The cultural capital attributes and design constraints of Yixing Zisha teapots

The design of Yixing Zisha teapots is not merely a geometric construction in three-dimensional space; it is also a materialised carrier of traditional Chinese literati tastes and exquisite craftsmanship. The classic theory of cultural economics holds that the value of 'cultural capital' encompasses both tradable economic attributes and multiple dimensions of cultural value, such as aesthetic symbols, spiritual significance, and the continuity of historical context (Zhao et al., 2023). Throughout its historical evolution, Zisha teapots have developed extremely strict physical and aesthetic constraints. Studies have shown that the visual proportions of Zisha teapots, functional components (the collinearity constraint of the spout, handle, and knob), and specific material language (such as the unique microscopic double air pores structure of Zisha material), together form the unique field of ICH (Norman, 2007; Chetana et al., 2024). However, current academic evaluations of Zisha teapot designs mostly remain at the level of semiotic semantic analysis or single qualitative criticism (Baheti and Gill, 2011; Mei et al., 2025), severely lacking a multi-dimensional assessment theory that can adapt to the requirements of digital systems, possess mathematical rigor and computational characteristics.

2.2 Application of fuzzy logic and MCDM in the evaluation of complex systems

In the assessment of cultural heritage, there is a widespread presence of subjective semantics and boundary ambiguity. Traditional Boolean binary logic is unable to capture the continuous state of human cognition. Since the introduction of the fuzzy set theory, the concept of degree of membership has been incorporated to provide a rigorous mathematical foundation for handling linguistic variables (such as 'very in line with tradition' and 'extremely unstable centre of gravity') (He et al., 2024). In multi-dimensional decision-making environments, the AHP is a classic MCDM tool that can transform complex qualitative decision-making networks into quantitative weight matrices (Salehipour et al., 2025). In recent years, a large number of studies have confirmed the outstanding performance of the combination of AHP and fuzzy logic (AHP-FCE) in handling unstructured data and reducing cognitive biases. Relevant research has successfully applied it to the comprehensive benefit assessment of green buildings (Karabulut et al., 2024), the assessment of multi-agent collaborative control (Hu et al., 2025), the quantification of the authenticity loss of cultural heritage (Poornima and Prakash, 2025), and the networked evaluation of cultural tourism resources (Guo et al., 2025; He et al., 2025). However, most of the existing fuzzy evaluation models are used as static terminal decision-making tools and are rarely embedded in dynamic evolving design generation loops to play a feedback regulation role.

2.3 CPSs and cultural heritage informatics

At the forefront of systems and control science, CPS and information-based control theories are penetrating into cultural heritage informatics with unprecedented depth (Saaty, 2002; Cappai et al., 2024). The CPS architecture based on the Internet of Things, digital twins, and multi-sensor data fusion enables the monitoring and active feedback of the life cycle of tangible and intangible heritage (Zheng et al., 2022). In line with this interdisciplinary trend, this study argues that the assessment of Zisha teapot designs should not exist in isolation but should be abstracted as a NCS. In this topological structure, the AIGC engine is the controlled object, the expert's cultural cognition is the reference input, and the GT-AHP-FCE model proposed in this paper acts as the core controller, using the fuzzy rule base to process the input design states and output quantified deviations to guide subsequent model fine-tuning and optimisation algorithms (Zhao et al., 2024).

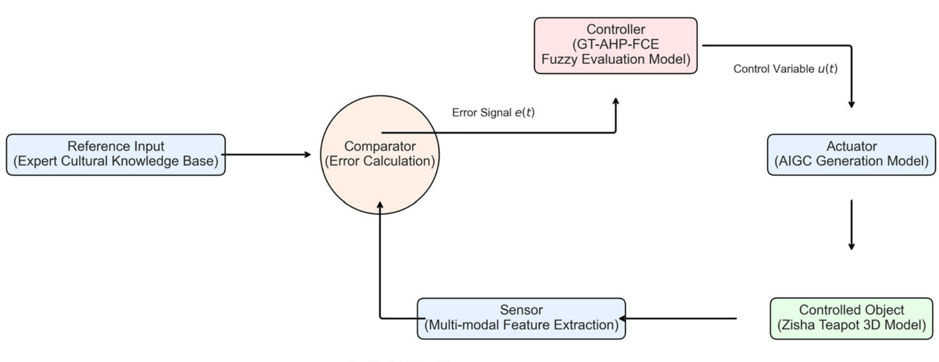
3 System modelling and evaluation architecture design

This section elaborates in detail on the control system architecture design of the intelligent fuzzy evaluation model, as well as the construction of the observation index system based on qualitative research.

3.1 System architecture design based on CPS metaphor

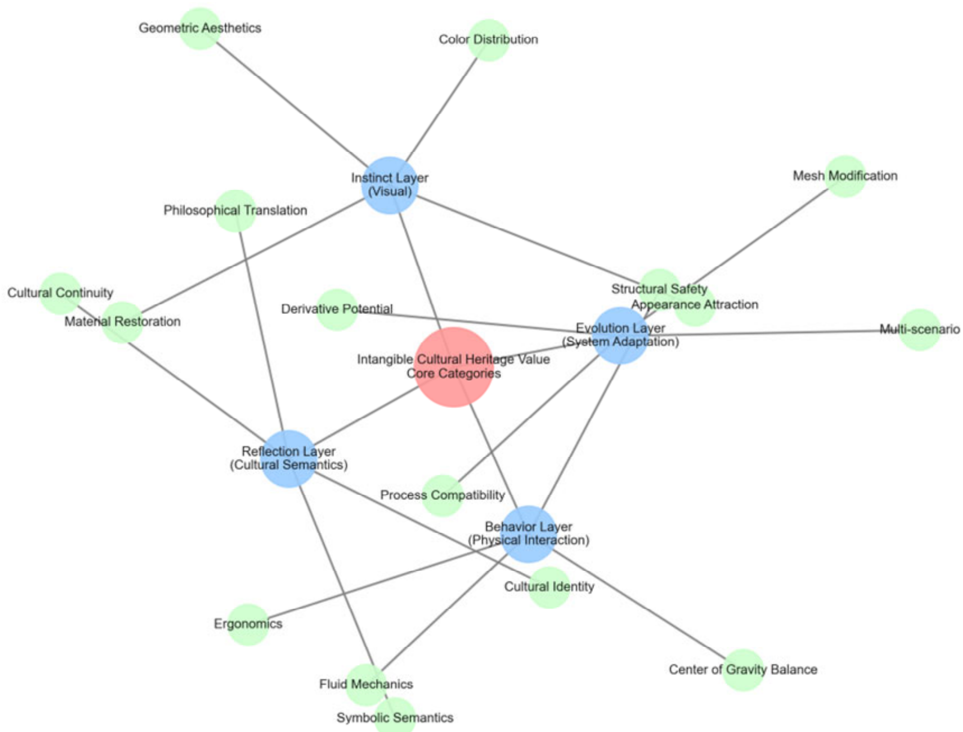
To achieve the closed-loop control generated by the design, this study has constructed a logical architecture that maps to the information-physical system (Figure 1).

Figure 1 Closed-loop feedback control architecture for AIGC Yixing Zisha teapot design based on CPS (see online version for colours)



In this architecture, the fuzzy evaluation model not only provides a single ‘good or bad’ judgment, but also outputs multi-dimensional state deviation vectors (for example: excellent visual performance, but the physical centre of gravity index deviates from the safety threshold), thereby achieving precise disturbance rejection.

Figure 2 Three-level coding of GT and core category association network (see online version for colours)



3.2 Dimension reduction of evaluation state space based on GT

Constructing a state space (indicator system) that conforms to the characteristics of Yixing Zisha is a prerequisite for system operation. This study employs GT as a tool for reducing qualitative data to eliminate preconceived biases (Baheti and Gill, 2011; Pan et al., 2025). Through organising focus groups consisting of national-level craft artists, cultural scholars, and industrial design experts for semi-structured interviews, a large amount of evaluation text data was collected, and open coding, axial coding, and selective coding were conducted (Figure 2).

Based on the classic emotion design theory framework (Zhao et al., 2025) and the coding results, the system ultimately constructed an evaluation index system $U = \{U_1, U_2, U_3, U_4\}$ consisting of four first-level state variables and 17 second-level observation variables:

- Instinctive state (visual aesthetics, U_1): appearance attractiveness (u_{11}), geometric aesthetics of form (u_{12}), proportional coordination (u_{13}), material texture reproduction (u_{14}), and colour and decoration distribution (u_{15}).
- Behavioural state (physics and interaction, U_2): Fluid mechanics and water ejection performance (u_{21}), centre of gravity and mechanical balance (u_{22}), human-computer interaction engineering (u_{23}), and structural safety (u_{24}).
- Reflective state (cultural semantics, U_3): Continuity of historical context (u_{31}), accuracy of symbolic semantics (u_{32}), cultural identification (u_{33}), and contemporary transcription of traditional philosophy (u_{34}).
- Evolutionary state (system adaptability, U_4): Parametric mesh modifiability (u_{41}), compatibility with real manufacturing processes constraints (u_{42}), adaptability of multi-scenario digital twins (u_{43}), and potential for secondary derivatives and expansion (u_{44}) (Norman, 2007; Pan et al., 2025).

4 Mathematical derivation of intelligent fuzzy evaluation algorithm

This section provides a rigorous mathematical formalisation for the AHP weight allocation within the controller and the FCE fuzzy state reasoning engine.

4.1 Calculation of the global weight matrix in AHP

The complex evaluation targets are decomposed into a hierarchical model, as shown in Figure 3.

Invite experts to establish pairwise comparison judgment matrices A for indicators at the same level. According to the 1–9 scale method, element a_{ij} represents the importance of element i relative to element j. The judgment matrix A is defined as follows [equation (1)]:

$$A = \left[a_{(ij)}\right]_{(n\times n)},\ a_{(ji)} = 1/a_{(ij)},\ a_{(ii)} = 1 \tag{1}$$

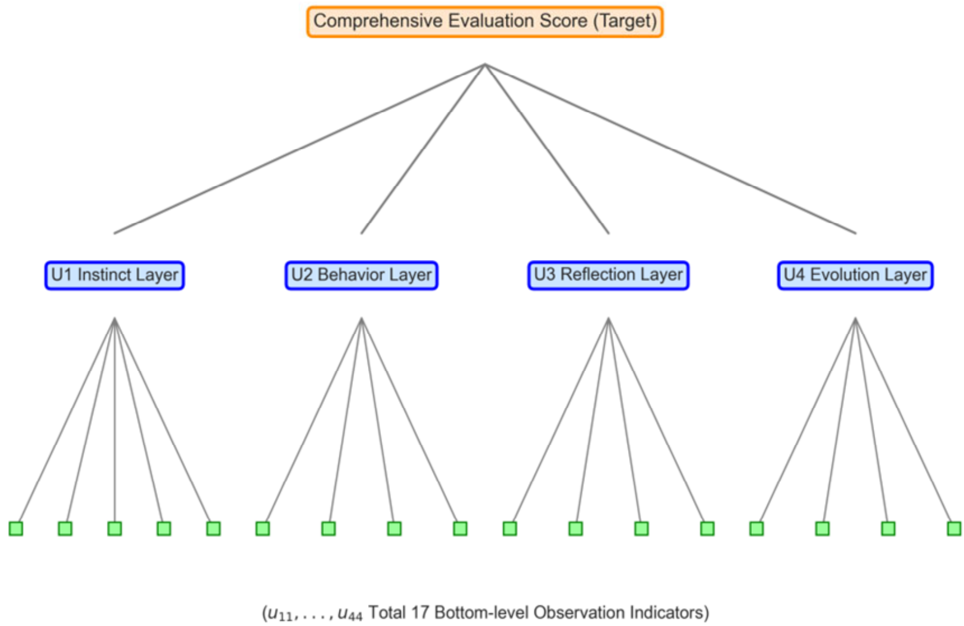
Determine the maximum eigenvalue $\lambda_{\max}$ of the judgment matrix and its corresponding eigenvector W. The equation to be solved is $AW = \lambda_{\max}W$. To ensure the robustness of the control system and the consistency with the expert's judgment, a consistency check must be conducted. Calculate the consistency index CI and the consistency ratio CR [equations (2) and (3)]:

$$CI = (\lambda_{\max} - n)/(n-1) \tag{2}$$

$$CR = CI/RI \tag{3}$$

Here, RI represents the average random consistency index. When and only when $CR < 0.10$. It is considered that the judgment matrix has satisfactory consistency. After normalisation, the eigenvector W becomes the local weight vector of each indicator (Salehipour et al., 2025).

Figure 3 Hierarchical structure for evaluating the cultural heritage value of AIGC Yixing Zisha teapots (see online version for colours)



4.2 Derivation of FCE operator

To address the subjective uncertainty in qualitative evaluation, the evaluation domain set (evaluation term set) is defined as a five-level Likert scale $V = \{V_1, V_2, V_3, V_4, V_5\} = \{extremely, high, medium, low, extremely\}$. The system assigns it a continuous reference score vector $S_v = [95, 85, 76, 65, 55]^T$.

To smooth the boundary effect, a fuzzy membership function (membership functions) is constructed by combining the Gaussian distribution function (for the intermediate state) and the trapezoidal distribution function (for the extreme state). For an evaluation score x and a certain comment k, the Gaussian membership degree is defined as [equation (4)]:

$$w_{ij}(x) = \exp\left(-\frac{(x - a_{ij})^2}{2\sigma_{ij}^2}\right) \tag{4}$$

Here, c_k represents the class centre, and σ_k is the variance parameter that reflects the degree of fuzziness (Figure 4).

A team of experts evaluated a specific design scheme and calculated the frequency of each indicator falling into each evaluation grade. After normalisation, a local fuzzy relation matrix R_i was formed. Taking the first-level indicator U_i as an example, its fuzzy relation matrix is [equation (5)]:

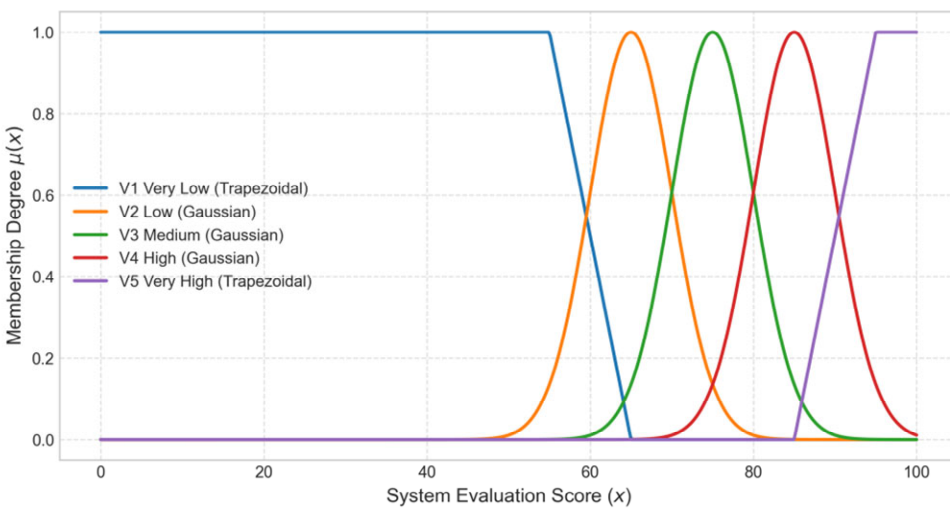
$$R = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15} \\ r_{21} & r_{22} & r_{23} & r_{24} & r_{25} \\ r_{31} & r_{32} & r_{33} & r_{34} & r_{35} \\ r_{41} & r_{42} & r_{43} & r_{44} & r_{45} \\ r_{51} & r_{52} & r_{53} & r_{54} & r_{55} \end{bmatrix} \quad (5)$$

By using the fuzzy synthesis operator, the weight vector W_i is multiplied with the fuzzy relation matrix R_i in a matrix operation to obtain the fuzzy evaluation vector B_i of the first-level indicators [equation (6)]:

$$B_i = W_i \circ R_i = \left(b_{i1}, b_{i2}, b_{i3}, b_{i4}, b_{i5}\right) \quad (6)$$

In this system, a weighted average type operator $M(., +)$ that takes into account global features is employed to prevent the loss of extreme value information. All B_i are combined to form the total fuzzy matrix R_{total} of the target layer, and then it is synthesised with the global weights W_{total} of the first-level indicators to obtain the final fuzzy output state vector B_{final} (Xu, 2024).

Figure 4 The Gaussian-trapezoidal combined fuzzy membership function curve of the comment set (see online version for colours)



Finally, in order to convert the fuzzy vector into a specific error signal that the control actuator can recognise, the centroid method (centre of gravity) is employed for defuzzification. The precise comprehensive crisp score S_i of the scheme is calculated as follows [equation (7)]:

$$S_i = \frac{\sum_{j=1}^{n} b_{ij} x_j}{\sum_{j=1}^{n} b_{ij}} \quad (7)$$

Here, n represents the total number of evaluation grades (in this case, $n = 5$). The variable b_{ij} denotes the fuzzy membership degree belonging to the j^{th} grade in the final fuzzy output state vector B_{final}, and x_j is the continuous reference score corresponding to the j^{th} evaluation grade (i.e., elements in the reference score vector S_v).

5 Experimental design and simulation analysis

5.1 AIGC design generation and experimental pre-settings

By modifying the prompt engineering and control parameters of the multimodal generative model, three distinct digital design schemes (plant inputs) representing different disturbance directions were generated for comparative evaluation:

- Scheme A (surreal parametric reconstruction): Incorporates complex modern topological optimisation curves, severely breaking traditional geometric constraints (e.g., exaggerated cantilever handles) to create a strong visual and mechanical disturbance.
- Scheme B (mixed cultural symbol concatenation): Forces the arbitrary implantation of unrelated cultural textures (e.g., Western sculpture motifs and bronze inscriptions) onto the teapot surface, serving to test the system's resistance under semantic and cultural noise disturbances.
- Scheme C (fine-tuning of classic pattern): Acts as the control baseline, performing only microscopic curvature optimisation on the historical classic 'Man Sheng' geometric mould, maintaining stringent traditional mechanical and aesthetic constraints.

A panel of 15 experts (consisting of five national-level craft artisans, five cultural heritage scholars, and five senior industrial designers, all with over five years of domain experience) was invited. Experts utilised a standardised five-level Likert scale to independently score the linguistic variables for each sub-indicator, which were then normalised to formulate the fuzzy relation matrix.

5.2 Analysis of AHP weight distribution

After rigorous expert scoring and matrix calculations, the global weight distribution of the target layer (first-level indicators) is shown in Table 1. Furthermore, the global weights of the 17 secondary observation indicators were calculated by multiplying the local weights of each secondary indicator (derived from their respective sub-level AHP judgment matrices) by the global weight of their corresponding first-level indicator. All sub-level judgment matrices strictly passed the consistency check ($CR < 0.10$). The final global weight distribution of the secondary indicators is presented in Table 1 and Figure 5.

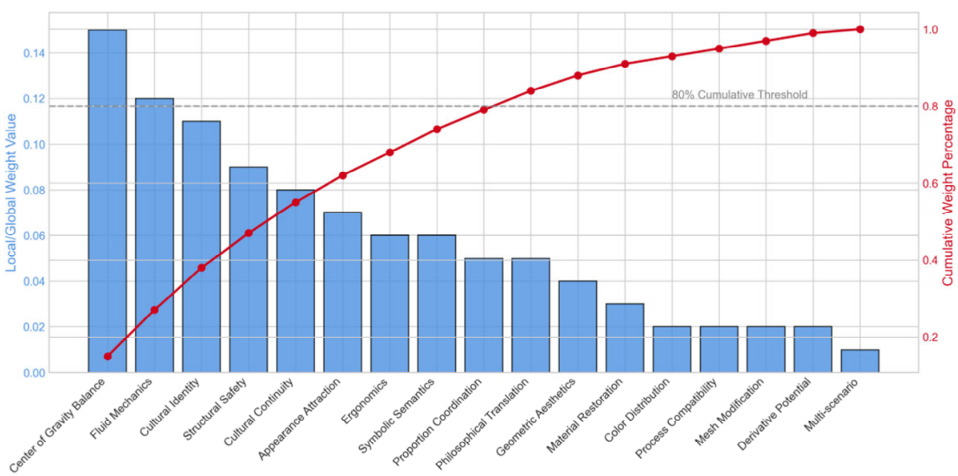
The data reveals the core control principle of the system: the physical interaction function at the behavioural level (0.444) and the cultural genes at the reflective level (0.283) constitute the absolute core of evaluation. This indicates that in the information-physical integration, digital assets still must be constrained by strict physical laws and long-term social and cultural consensus. The visual spectacle solely relying on the algorithmic computing power (the instinctive level accounts for only 0.165) cannot maintain the long-term stability of the system (Zhao et al., 2023).

Table 1 AHP judgment matrix for the first-level indicators and the calculation results of global weights

Target layer	U_1 *instinctive layer*	U_2 *behavioural layer*	U_3 *reflective layer*	U_4 *evolutionary layer*	*Local weight* (W_{total})
U_1 instinctive layer	1	1/3	1/2	2	0.165
U_2 behavioural layer	3	1	2	4	0.444
U_3 reflective layer	2	1/2	1	3	0.283
U_4 evolutionary layer	1/2	1/4	1/3	1	0.108

Notes: The maximum eigenvalue of the matrix $\lambda_{MAX} = 4.0458$, $CI = 0.0153$, $CR = 0.0172 < 0.10$.

Figure 5 Pareto chart showing the global weight distribution of 17 secondary observation indicators (see online version for colours)



5.3 *Fuzzy state transition and multidimensional result analysis*

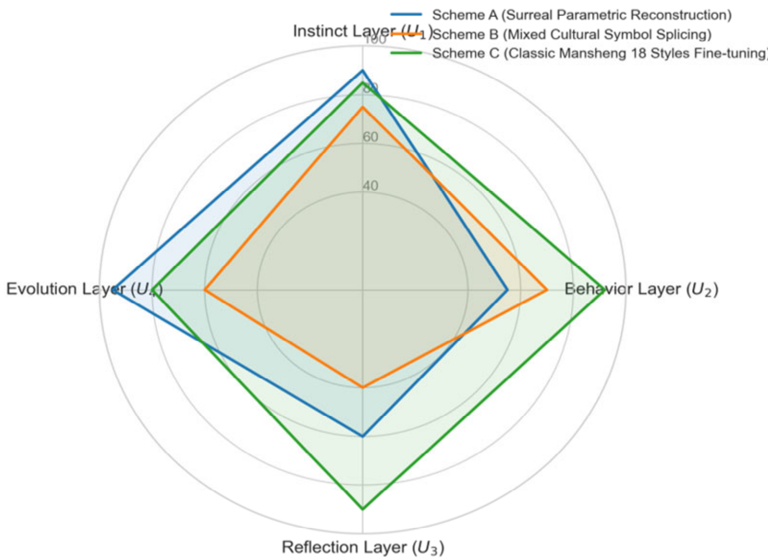
By substituting the expert sensing data into the membership function and through multi-level fuzzy synthesis, the system produced a state profile of the three schemes in four dimensions (Figure 6).

- Scheme A (parametric reconstruction): Exhibits excellent performance in the system evolution potential (U_4), but suffers from severe state deviation in the behavioural layer (U_2). The excessive pursuit of exaggerated cantilever structures leads to the system's centre of gravity being extremely prone to overturning, and the mechanical equilibrium state being in a critical dangerous zone (Wang, 2025).
- Scheme B (symbol concatenation): The membership matrix operation results in the reflection layer (U_3) concentrating in the 'extremely low' and 'low' domains, and the fuzzy vector is (0.05, 0.12, 0.23, 0.45, 0.15). This indicates that this option has

produced a serious cultural semantic rejection reaction, and the system identifies it as 'false heritage innovation' noise interference (Poornima and Prakash, 2025).

- Scheme C (classical fine-tuning): The state is the most stable. The main energy of the fuzzy synthesis is concentrated in the 'high' and 'extremely high' domains.

Figure 6 Comparison of the comprehensive evaluation radar charts of the three schemes across the four state dimensions (see online version for colours)



5.4 *Performance convergence and optimisation under closed-loop feedback mechanism*

The final defuzzification was carried out using the centre-of-gravity method, resulting in the final decision score of the system controller: scheme C (89.0 points) > scheme A (66.5 points) > scheme B (61.3 points) as shown in Figure 7.

In the context of NCSs, the evaluation results are not the final outcome but rather the initial feedback error for the next round of iteration. The crisp evaluation score is compared with the expert-set target domain (setpoint ≈ 85), and the mathematical difference is quantified as the feedback error $e(t)$. We extracted the dynamic correction curve for scheme A through algorithm simulation.

From the simulation trajectory in Figure 8, it can be seen that, under the action of the closed-loop mechanism, the system successfully suppressed geometric disturbances in the early stages of the generation model. Specifically, the evaluation controller encodes the negative deviation (such as 'low score in the behaviour layer' caused by centre-of-gravity issues) as a continuous penalty term in the gradient descent optimisation of the generation model. This explicit error signal forces the AI actuator to adaptively adjust the quality distribution parameters of the handle and the spout, ultimately making the output signal converge to the set value expected by the expert (Nisiotis et al., 2025).

For the closed-loop simulation (Figure 8), the dynamic iteration was set with a maximum of 50 epochs. The stopping criterion was defined as the system comprehensive score stabilising within a ±1% error margin around the expert-set target domain (setpoint ~ 85) for five consecutive epochs.

Figure 7 A stacked bar chart showing the multi-dimensional score breakdown of three AIGC designs for Yixing Zisha teapots (see online version for colours)

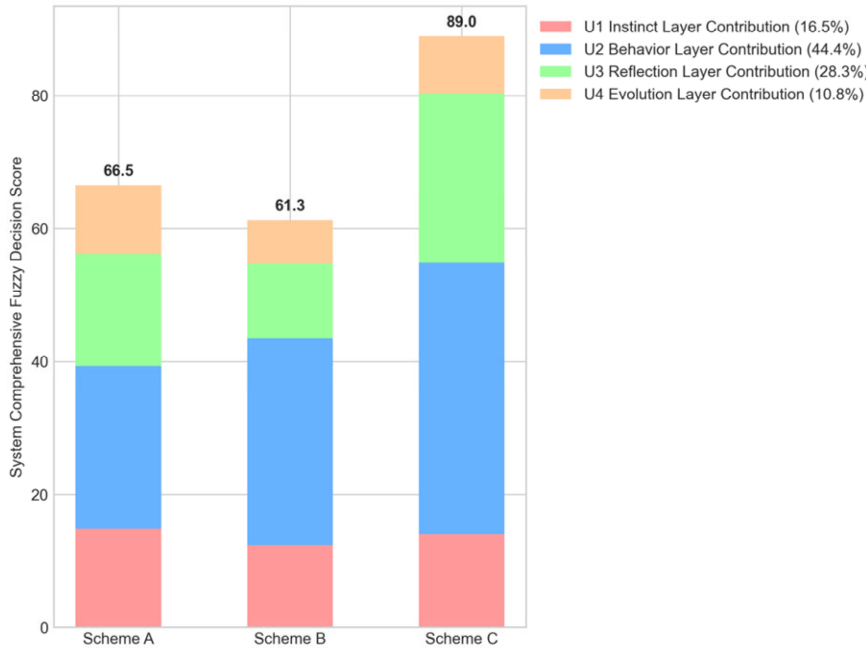
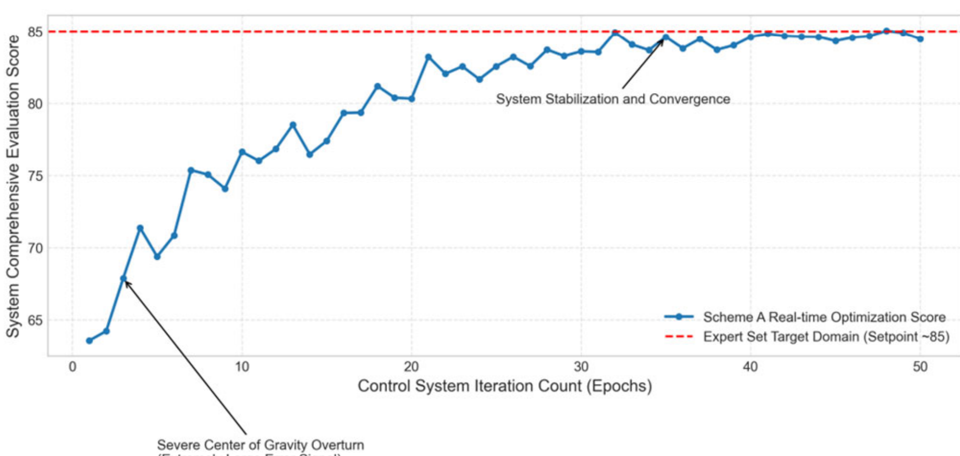


Figure 8 Convergence curve of the design iteration of scheme A based on evaluation feedback (see online version for colours)



6 Discussion

6.1 The significance of the information control architecture in overcoming the non-structured cognitive gap

The highly personalised characteristic of traditional Zisha teapot evaluation, which belongs to the unmanageable non-structured dark data in data science (Baheti and Gill, 2011), is addressed by the proposed GT-AHP-FCE model. The continuous membership function combining Gaussian and trapezoidal shapes precisely captures the complex psychological probability distribution of the shift between 'breaking through the deadlock' and 'preserving the tradition' by the experts in the craft, effectively avoiding the nonlinear severe oscillations caused by binary hard threshold control (Xu, 2024; Karabulut et al., 2024). This method of converting implicit cultural genes into explicit matrix parameters provides a standard protocol for constructing large-scale ICH knowledge graphs and computational ontologies (Cappai et al., 2024).

6.2 Robustness to disturbances and the scalability of multi-agent systems

This study has demonstrated that the control system exhibits an extremely strong ability to resist semantic disturbances. When confronted with outputs such as scheme B, which masquerades as 'innovation' but actually undermines core values, the system can precisely filter out noise through high-weight cultural state variables. Moreover, in the future architecture of the metaverse based on multi-agent systems (MASs) (Nisiotis et al., 2025), the computational model presented in this paper can be rapidly replicated and deployed as decentralised 'digital supervisory nodes'. Different nodes can load expert weight parameters of different schools of thought, enabling diversified parallel evaluations, which significantly expands the universality and scalability of this theory in the evolution of complex cultural ecosystems (Hu et al., 2025).

6.3 Human-in-the-loop (human-computer collaboration): preventing pure technological determinism

The high weight of the model is concentrated on the reflection and behaviour layers, deeply touching upon the core propositions in the digitalisation process. Although computing power is growing exponentially, in the ICH fields involving human emotions and deep historical memories, we must be vigilant against pure technological determinism and algorithm worship (Zhao et al., 2023; Zheng et al., 2022). The closed-loop system of this study demonstrates the necessity of 'human-in-the-loop': AIGC is responsible for expanding the breadth and speed of the optimisation of design schemes, while human experts firmly hold the steering wheel of the evaluation controller by controlling the value weights of the AHP judgment matrix, safeguarding the intrinsic essence of the authenticity of ICH (Gu and Hein, 2023).

6.4 Methodological advantages over traditional MCDM methods

Compared to conventional MCDM methods such as TOPSIS or basic Delphi-AHP, the proposed GT-AHP-FCE model demonstrates significant advantages in handling boundary ambiguity. While TOPSIS relies on strict geometric distances to ideal solutions – which often fail to capture continuous aesthetic perception – our model utilises a Gaussian-trapezoidal combined fuzzy membership function. This allows for a smoother transition in evaluation domains, accurately mapping complex, subjective human cognitive states into precise control signals for generative optimisation.

7 Conclusions and future prospects

This research has integrated perspectives from art humanities and information control engineering, successfully establishing an intelligent fuzzy evaluation and feedback control model based on the GT-AHP-FCE framework. This model has broken through the bottleneck of traditional subjective qualitative evaluation of ICH, providing a digital ruler with both rigorous mathematical foundation and high cultural sensitivity for AIGC Yixing Zisha teapot design. The experimental data indicate that under the information-physical integration paradigm, this evaluation model can effectively act as the core controller in the network loop, real-time quantitatively outputting state deviations, highly faithfully filtering digital generation disturbances, and driving the AIGC system to converge towards the Pareto optimal boundary that combines physical practicality and cultural inheritance.

In future research and engineering deployments, we will strive to deeply integrate this assessment framework with physical networks (IoT) sensing devices. For instance, by embedding miniature pressure and temperature sensor arrays in physical Yixing Zisha prototype components, we can collect the human-computer interaction timing data at the real user end. Then, using machine learning algorithms, we can achieve online adaptive updates and dynamic reconstructions of fuzzy rule libraries and weight matrices (Chetana et al., 2024; Guo et al., 2025). Moreover, exploring the integration of assessment and knowledge ownership mechanisms onto a decentralised network will provide a more solid system science foundation for the secure circulation and continuous innovation of digital cultural capital in the global information network.

This research provides two major contributions: theoretically, it extends the CPSs framework into the realm of ICH, conceptualising cultural assessment as a dynamic networked control problem; practically, it prevents the alienation of traditional cultural genes in AI-driven generation, offering a scalable decision-making protocol for the global circulation of digital cultural capital.

Declarations

Informed consent was obtained from all experts and artisans involved in the focus groups, semi-structured interviews, and evaluation scoring. Participants were fully informed of the study's purpose, and their data was anonymised prior to analysis.

All authors declare that they have no conflicts of interest.

My research did not involve human participants.

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